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DOUGLAS MDC J4505

ENGINE/AIRFRAME COMPATIBILITY STUDIES FOR SUPERSONIC CRUISE AIRCRAFT

SUPPLEMENTAL REPORT

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LANGLEY STATION, HAMPTON, VIRGINIA

MCDONNEL DOUGLAS CORPORATION

DOUGLAS AIRCRAFT COMPANY - LONG BEACH

FOREWORD

This document presents the results of a supplementary contract study, entitled "Engine/Airframe Compatibility Studies for Supersonic Cruise Aircraft", performed for NASA by the Douglas Aircraft Company, McDonnell Douglas Corporation.

The NASA technical monitor for the study was F. E. McLean, Supersonic Cruise Aircraft Research Program Office, Langley Research Center, Hampton, Virginia.

This study program was under the overall direction of R. D. FitzSimmons, Director, Advanced Supersonic Transport. The Technical Manager was W. T. Rowe. This report consists of results of in-depth analyses of a supersonic transport configuration with an alternate engine (P&WA variable stream control) integrated in place of the baseline dry turbojet engine.

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SYMBOLS AND ABBREVIATIONS

A.C., a.c.	Aerodynamic Center
A_c	Inlet Capture Area
A_o	Freestream Capture Area
A_o/A_c	Mass-flow Ratio
$A_o/A_c)_{bleed}$	Mass-flow Ratio of Inlet Bleed Flow
BPR	Bypass Ratio
BTU	British Thermal Unit
c	Local Wing Chord
$\bar{c}$	Mean Aerodynamic Chord
°C	Temperature-Celsius
C_D	Drag Coefficient = $\frac{D}{q_o S_{ref}}$
CET	Combustor Exit Temperature
C.G., c.g.	Center of Gravity
cm	Centimeter
D	Drag, Diameter
D_{AFT}	Afterbody Drag
DAC	Douglas Aircraft Company
EAS	Equivalent Air Speed
EPNdB	Effective Perceived Noise in Decibels
FT	Feet
°F	Temperature-Fahrenheit
F_G	Gross Thrust
F_N	Net Thrust
FAR Part 36	Federal Aviation Regulation for Noise
fps	Feet per Second
g	Acceleration of Gravity

SYMBOLS AND ABBREVIATIONS (continued)

GE	General Electric
gm	Gram
HR	Hour
in	Inches
ITS	Inverse Temperature Schedule
J	Joules
°K	Temperature-Kelvin
k	Kilo
KEAS	Knots Equivalent Air Speed
kg	Kilograms
km	Kilometers
kW	Kilowatts
LB	Pounds
L/D	Lift to Drag Ratio
m	Meters
M	Mach Number
N	Newtons
NASA	National Aeronautics and Space Administration
N.MI., n.mi.	Nautical Miles
P&WA	Pratt & Whitney Aircraft
PNdB	Perceived Noise - Decibels
PNL	Perceived Noise Level
PPS	Pounds per Second
P_{amb}	Ambient Pressure
P_o	Sea Level Pressure, 2116.2 LB/FT^2 (10.1325 N/cm^2)
P_{to}	Freestream Total Pressure

SYMBOLS AND ABBREVIATIONS (Concluded)

P_{t2}	Average Compressor Face Total Pressure
P_{t2}/P_{to}	Inlet Total Pressure Recovery
q	Freestream Dynamic Pressure, $1/2\, \rho V^2$
sec	Seconds
SFC	Specific Fuel Consumption
SL	Sea Level
SLS	Sea Level Static
Std	Standard
V	Velocity
V_j	Jet Velocity
T_{amb}	Static Temperature
T_o	Sea Level Static Temperature, 518.7°F (288.16°K)
T_{t2}	Inlet Total Temperature
VCE	Variable Cycle Engine
VSCE	Variable Stream Control Engine
W	Weight
W_a	Engine Airflow
WAT2	Corrected Inlet Airflow
W_f	Engine Fuel Flow
$\Delta X_{a.c.}$	Change in Aerodynamic Center Location
"	Inches
%	Percent
δ_{amb}	Pressure Ratio, P_{amb}/P_o
δ_{t2}	Pressure Ratio, P_{t2}/P_o

INTRODUCTION

During 1974, the Douglas Aircraft Company (DAC), McDonnell Douglas Corporation, conducted studies for NASA to integrate several of the most promising advanced technology concept engines in a well established baseline airplane configuration. These engines had been defined by the major U.S. engine manufacturers under separate NASA contract. The primary purpose of the effort is to define the correct engine cycle so that development can be initiated at the earliest possible date, since the engine seems to be the pacing item for any new supersonic transport program.

The results of the 1974 studies are reported in NASA Report No. CR 132610 (DAC Report No. MDC J4478), "Engine/Airframe Compatibility Studies for Supersonic Cruise Aircraft". The specific engine cycles studied and reported include the mini-bypass turbojet, duct heating turbofan, and the dual valve variable cycle. The basis for comparison is the DAC baseline configuration conceptual design which is powered by a 1975 technology dry turbojet engine and is defined in detail in the report.

This supplemental report describes the effort and results of integrating a version of a duct heating turbofan configuration (P&WA 502 variable stream control engine, as modified by DAC hereafter called P&WA 502D) in the baseline airplane. The P&WA 502D should not be confused with the engine adapted for Boeing (P&WA 502B) and which has not been studied by Douglas. Results are presented in the same format as the original report to facilitate direct comparison of charts. In addition, the Summary, Conclusions, and Recommendations paragraphs of the original report are repeated herein with revisions to incorporate the findings of the variable stream control engine study of the P&WA 502D.

SUMMARY

Engine/airframe compatibility studies have been completed utilizing the DAC advanced supersonic transport point design as the baseline for comparison. After analysis of many options, a specific engine design was selected for each of four types of engine cycles and a careful engine airframe integration study completed for each relative to the point design airplane. The engines selected for detail study are as follows:

- Mini-bypass turbojet: GE P7 engine
- Duct heating turbofan: P&WA 501D engine
- Valved variable cycle: P&WA 302B engine
- Variable stream control: P&WA 502D engine (VSCE)

These engines were selected as the best available within the time frame of this study and are reported on as offered without any technology normalizing between supplying engine companies or within a specific company.

This effort has been accomplished under NASA contract No. 1-13229. This report fulfills the requirement for a final summary report on this effort.

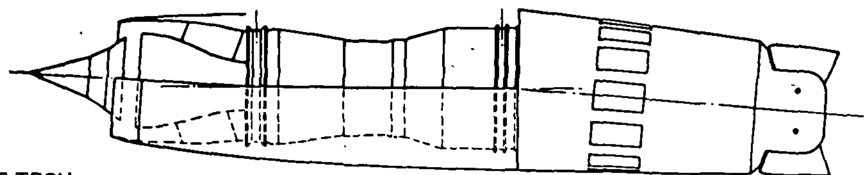
These studies entail a preliminary design process which integrates the technical variations necessary to size the candidate engines, define the nacelle and airplane geometry, determine new aerodynamic, propulsion and weight efficiencies, and then assess the resulting performance and acoustics characteristics as compared with the base point design airplane [750,000 lb. (340,194 kg) takeoff gross weight, 10,000 ft.^{2} (929m^2) wing area, and 273 passengers]. The initial engine sizing constraint used for the study is that each study engine produce a takeoff thrust at 0.3 Mach equivalent to the reference airplane engine with sideline and takeoff/cutback noise not to exceed FAR Part 36. This sizing is later validated by determining the engine size which provides best range.

The method used in the acoustics evaluation of the engines during the study is to calculate the unsuppressed source noise knowing the engine details plus the gas flow data provided for the particular engine operating conditions. These inputs are based on engine cycle data supplied by the engine manufacturers, as part of their contract efforts with NASA Lewis. Incremental jet noise suppression values applied to the unsuppressed jet noise levels are based on suppression characteristics supplied by each engine manufacturer for his engine cycle and recommended method of application. Later information from one engine manufacturer indicated a reduction in suppression levels based on recent test data corrected for forward flight effects. As a result, information is included considering the DAC baseline configuration nozzle/suppressor/reverser exhaust system, including effects of forward flight on that particular engine.

It is estimated that the approach noise levels are of the same order of magnitude as those for the baseline configuration and less than FAR Part 36 requirements.

The technical analysis, configuration descriptions, and study results are presented herein or in Report CR 132610 by technology or multi-technology area of responsibility for each of the four specific engines studied.

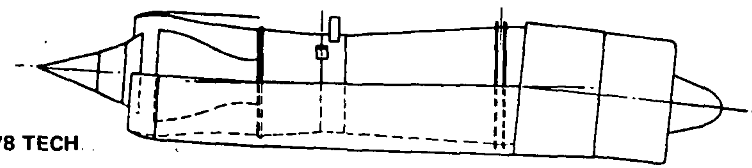
A summary chart illustrating the resulting sizes required for the various engines studied is presented in Figure S-1. A summary of takeoff performance is shown in Table S-1, and a noise summary is provided in Table S-2. Specific fuel consumption data are summarized in Table S-3 and the relative ranges in Figure S-2. The variation in operators' weight, L/D and range with engine size for the study engines is summarized in Figure S-3. All the engine sizes identified in Figure S-3, except the VSCE, are the minimum sized engines



1975 TECH

BASELINE TURBOJET ENGINE
AIRFLOW 773 LB/SEC (351 kg/SEC)

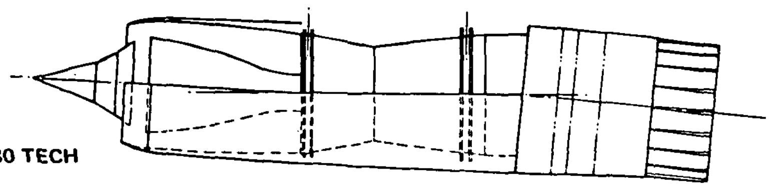
WEIGHT (ENGINE AND NOZZLE)	16,982 LB (7679 kg)
LENGTH (INTAKE FACE TO NOZZLE)	438.5 IN. (11.1 m)
MAX DIAMETER	97.0 IN. (2.5 m)
SLS THRUST	73,200 LB (326 kN)



1978 TECH

MINI-BYPASS ENGINE
AIRFLOW 782 LB/SEC (355 kg/SEC)

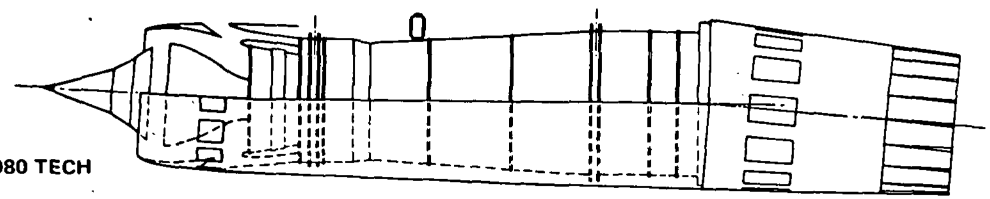
WEIGHT (ENGINE AND NOZZLE)	14,413 LB (6538 kg)
LENGTH (INTAKE FACE TO NOZZLE)	359.5 IN. (9.1 m)
MAX DIAMETER	81.0 IN. (2.06 m)
SLS THRUST	74,700 LB (332 kN)



1980 TECH

DUCT HEATING TURBOFAN ENGINE
AIRFLOW 875 LB/SEC (397 kg/SEC)

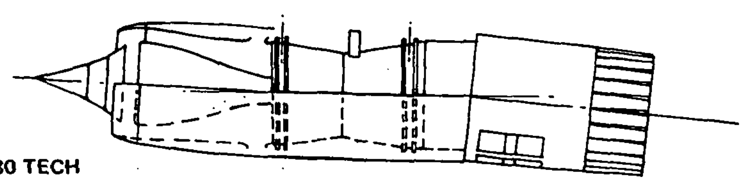
WEIGHT (ENGINE AND NOZZLE)	12,200 LB (5543 kg)
LENGTH (INTAKE FACE TO NOZZLE)	358.5 IN. (9.1 m)
MAX DIAMETER	86.8 IN. (2.2 m)
SLS THRUST	70,000 LB (314.5 kN)



1980 TECH

VARIABLE CYCLE ENGINE – DUAL VALVE
AIRFLOW 1003 LB/SEC (455 kg/SEC)

WEIGHT (ENGINE AND NOZZLE)	19,575 LB (8879 kg)
LENGTH (INTAKE FACE TO NOZZLE)	496.89 IN. (12.6 m)
MAX DIAMETER	100.23 IN. (2.5 m)
SLS THRUST	58,050 LB (258 kN)



1980 TECH

VARIABLE STREAM CONTROL ENGINE – 502D
AIRFLOW 725 LB/SEC (329 kg/SEC)

WEIGHT (ENGINE AND NOZZLE)	9,836 LB (4461.6 kg)
LENGTH (INTAKE FACE TO NOZZLE)	325.1 IN. (8.257 m)
MAX DIAMETER	79.0 IN. (2.007 m)
SLS THRUST	53,773 LB (239.19 kN)

FIGURE S-1. ENGINE SUMMARY

TABLE S-1
TAKEOFF SUMMARY

	BASELINE TURBOJET -5A	MINI-BYPASS -5B	DH/TF -5C	VCE DUAL VALVE -5D	VSCE 502D -5G
FIELD LENGTH (FT)	10,700 (3261 m)	10,850 (3307 m)	11,200 (3383 m)	11,000 (3350 m)	10,850 (3307 m)
HEIGHT AT 3.5 N MI (FT)	1,256 (383 m)	1,292 (394 m)	1,268 (386 m)	1,225 (373 m)	1,380 (420 m)

TABLE S-2
NOISE SUMMARY

FAR PART 36 NOISE LEVELS/FAR PART 36 NOISE REQUIREMENTS, EPNdB

ENGINE TYPE	SIDELINE	CUTBACK
DAC DRY TURBOJET (-5A)	104/–4	105/–3
GE P7 WITH 15 EPNdB SUPPRESSOR	102/–6	107/–1
GE P7 WITH 12 EPNdB SUPPRESSOR (-5B)	105/–3	110/+2
GE P7 WITH DAC SUPPRESSOR	106/–2	110/+2
DUCT HEATING TURBOFAN (-5C)	108/0	108/0
VARIABLE CYCLE 302B (-5D)	107/–1	106/–2
VARIABLE STREAM CONTROL ENGINE 502D(-5G)	105/–3	105/–3

TABLE S-3
ENGINE SFC SUMMARY

	BASELINE TURBOJET	MINI-BYPASS	DH/TF	VCE DUAL VALVE	VSCE 502D
CLIMB SFC, UNINSTALLED [1.57M, 40K FT (12,192m)]	1.165	1.182	1.350	1.380	1.500
CLIMB SFC, INSTALLED [1.57M, 40K FT (12,192m)]	1.258	1.227	1.546	1.593	1.569
SUBSONIC CRUISE, UNINSTALLED [0.93M, 30K FT (9,144m)	1.150	1.075	1.050	1.050	1.020
SUBSONIC CRUISE, INSTALLED [0.93M, 30K FT (9,144m)]	1.420	1.195	1.320	1.300	1.220
SUPERSONIC CRUISE, UNINSTALLED (2.2M, AVG CR ALT)	1.270	1.270	1.455	1.350	1.360
SUPERSONIC CRUISE, INSTALLED (2.2M, AVG CR ALT)	1.376	1.348	1.644	1.496	1.469
HOLD, UNINSTALLED [0.55M, 15K FT (4,572m)]	1.350	1.165	0.980	0.960	0.990
HOLD, INSTALLED [0.55M, 15K FT (4,572m)]	1.440	1.229	1.110	1.130	1.060

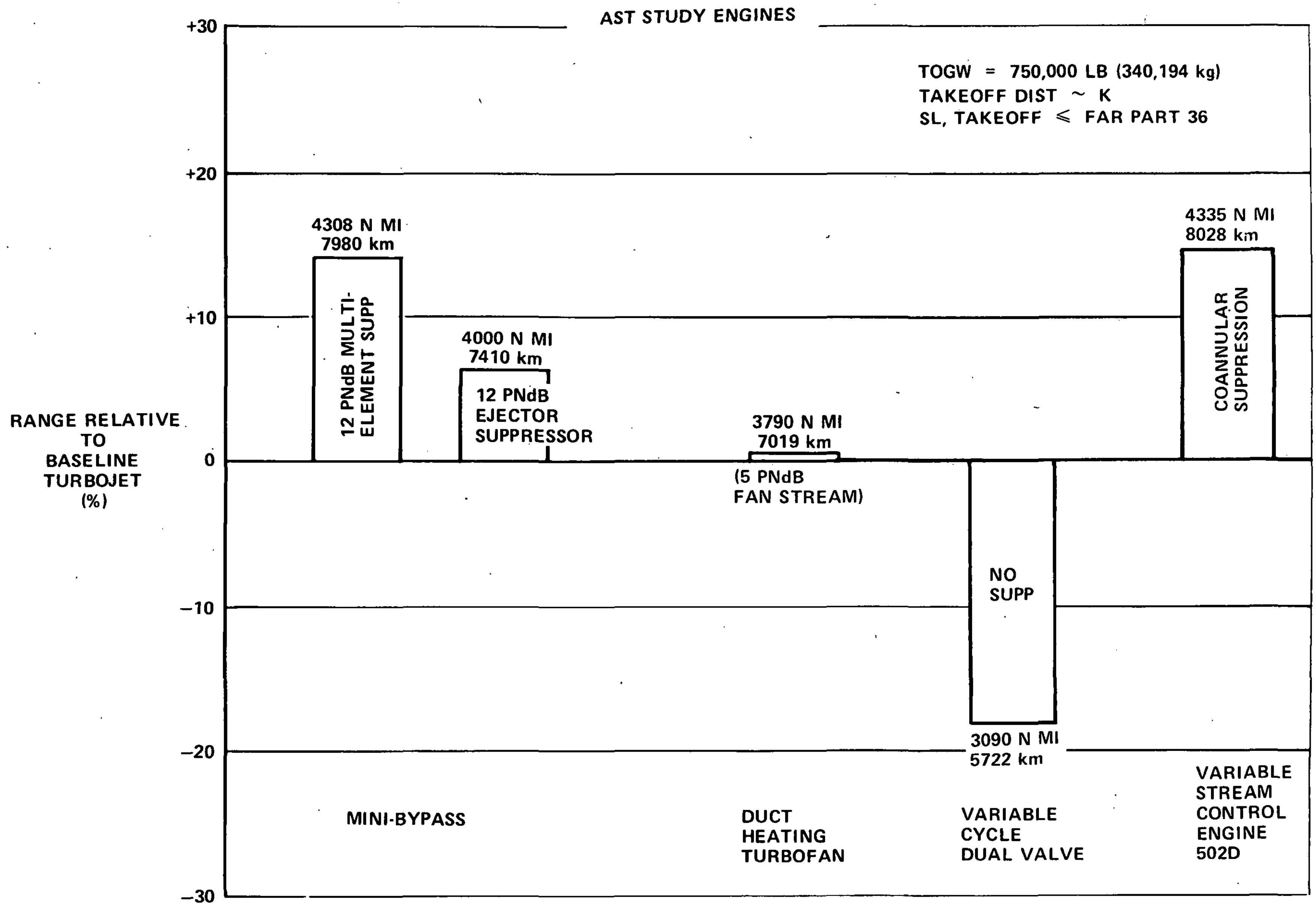


FIGURE S-2. RANGE COMPARISON

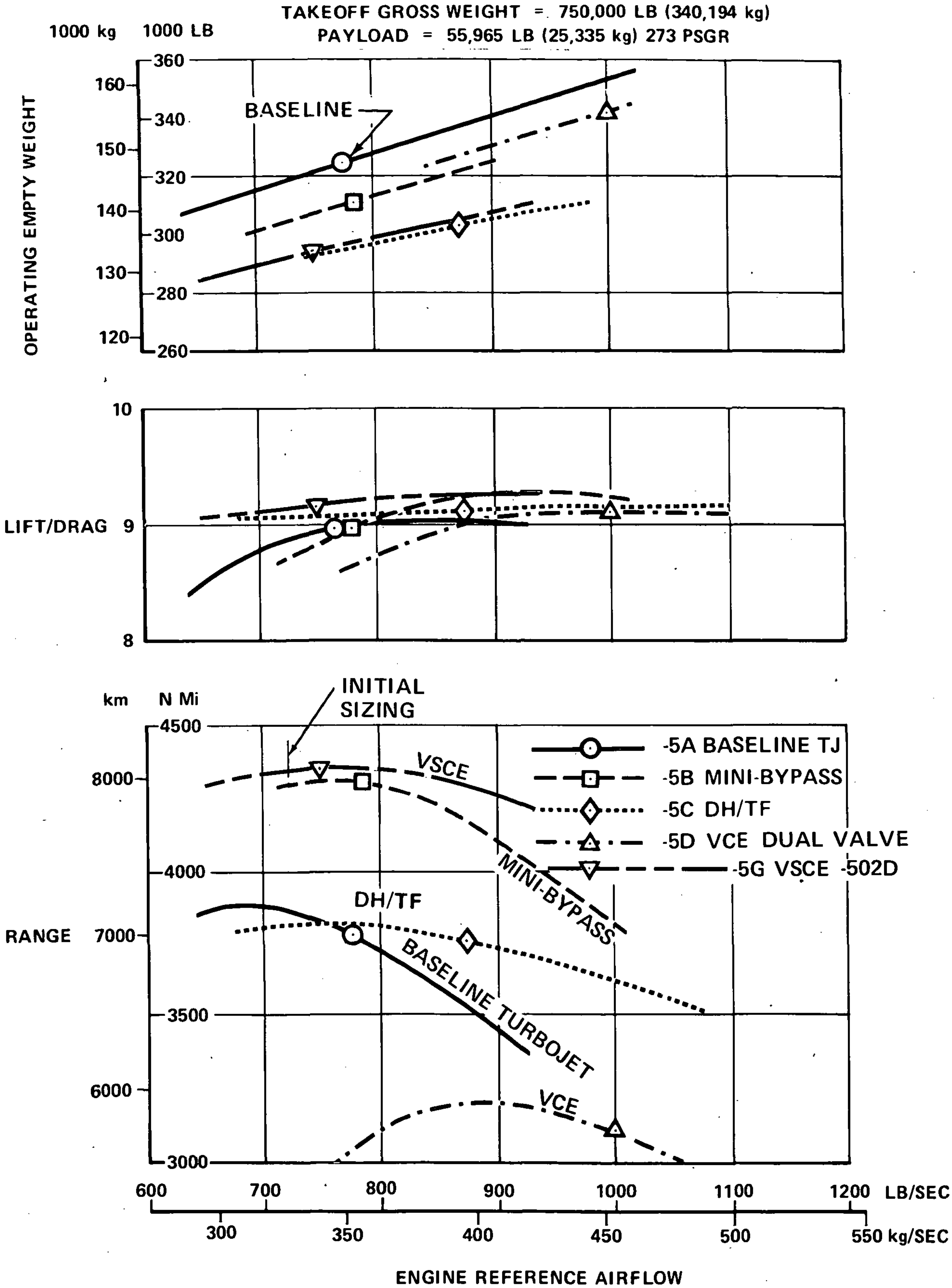


FIGURE S-3. ENGINE SIZING COMPARISON

meeting the initial sizing constraints. The minimum sized mini-bypass turbojet shows near-optimum range. The minimum sized duct heating turbofan is limited by the allowable suppressor temperature (Note: The coannular suppression effect could now be applied to this engine to eliminate the finger suppressor and resulting temperature limit). The VCE engine is sized at its maximum takeoff thrust, unthrottled, with no suppressor, and therefore cannot be sized smaller. The VSCE provides the maximum range at a slightly larger engine size than that required for noise. The larger size is chosen to take advantage of the maximum range point and the improved takeoff performance.

All engines studied in this report are stated by the engine manufacturers to be technically capable of design initiation in the 1978-1980 time period. With a normal development period, any selected engine would not permit initial commercial operations until the late 1980's, which is probably later than desired for an advanced U.S. supersonic transport.

CONCLUSIONS

The following summarizes the significant conclusions from these studies:

1. The engine data supplied by the engine manufacturers as part of the recent NASA study contracts offer significant performance improvements for an advanced supersonic cruise aircraft than was available one year ago. More range and slightly reduced noise are now shown to be possible.
2. Considering FAR Part 36 or FAR Part 36 minus two EPNdB as the AST noise requirements, either the mini-bypass turbojet cycle employing a plug nozzle/multi-chute suppressor exhaust system with a high level of jet noise suppression or the variable stream control engine with coannular suppression effect and lined ejector becomes the preferred AST engine based upon range performance. The mini-bypass selection is valid considering either degradation in effectiveness of the plug nozzle multi-chute suppressor type, or substitution of a DAC designed ejector nozzle/multi-element suppressor/reverser exhaust system which is estimated to have improved performance but higher weight and drag. The variable stream control engine is an excellent candidate, however, the coannular suppression effect needs validation with flight effects included prior to its final selection.
3. The duct heating turbofan cycle (P&WA 501) at approximately FAR Part 36 or FAR 36 minus two EPNdB noise levels offers approximately the same range as the baseline dry turbojet airplane. It has the advantage of relying on lower levels of noise suppression and as such may offer improved potential for further noise reductions as technology improves. Also, it is less sensitive to performance degradation for missions with subsonic legs. This cycle warrants further evaluation.
4. The dual valve variable cycle engines all result in range losses as compared to the baseline airplane and appear to warrant no further evaluation.

5. Data received from the engine companies since engine selections were finalized for the original study indicated that several improved technology engines were defined and ready for evaluation. The first of these, the P&WA 502D described herein, shows improved performance. The specific engines yet to be evaluated are the improved P&WA 502B variable stream control engine, the GE21/J9B2 double bypass dual cycle engine, the P&WA 405B low-bypass turbojet engine, and the P&WA 112B single (rear) valve VCE.
6. The figure-of-merit, range, as used in this study is only one way to compare engines. It must be remembered that other considerations are weighed carefully when airlines make engine selections. These include engine reliability, engine costs and operating costs. Also, items such as timing, minimizing fuel consumption, initial cost, maintainability, experience, commonality, and safety need evaluation. Such evaluations are beyond the scope of this study, but need to be considered when trying to narrow down the number of engine design types for further development.
7. Engine evaluations relative to suitability for mission performance must include detail installation design as detail design can have significant impact on the final result. Installation design, utilizing expertise unique to aircraft manufacturers, is required to insure the optimum, or best compromise, integrated propulsion system. Such items as propulsion control, cooling, integrated nozzle/reverser/suppressor, nacelle shape, and nacelle location must be addressed in close coordination with the engine companies. Only through analyses such as these can the engine be adequately evaluated as uninstalled data comparisons will not reveal the best configuration. Therefore, engine evaluations, comparisons and eventual selections should include the mission performance of the integrated airframe/propulsion systems.

RECOMMENDATIONS

1. Realizable noise suppression levels corrected for flight effects are critical parameters effecting engine cycle selection. Accordingly, tests to verify these noise levels should be consummated as soon as possible, including the following:

   - Coannular nozzle with acoustic lined ejector.
   - Plug nozzle multi-chute suppressor.
   - Multi-lobe/tube plug nozzle suppressor with an acoustic lined ejector.

2. The following engine design concepts need immediate evaluation and baseline airplane integration effort:

   a. The improved version of the variable stream control engine (502B) which offers improved SFC for both subsonic and supersonic cruise.

   b. A double bypass dual cycle concept with low jet exhaust noise for take-off and low SFC for supersonic cruise.

   c. A low bypass turbojet which offers improved SFC at supersonic cruise with a small size and light weight.

   d. A single valve concept with improved SFC for both subsonic and supersonic cruise.

3. Continuing airplane evaluation studies are recommended for advanced engine cycles as engine concept designs progress. This insures that realistic detail airplane installation design impacts will be accounted for in evolving engine designs.

4. The airframe manufacturer should work directly with the major international carriers to evaluate credibility of parameters for eventual engine selection.

SECTION 5

VARIABLE STREAM CONTROL ENGINE/ AIRPLANE CONFIGURATION

LIST OF FIGURES

LIST OF TABLES

ENGINE SELECTION

Section 3 of the basic report defines the analysis for the selection of a duct heating turbofan (DH/TF) for integration into the baseline airplane configuration. The specific engine selected and used is the P&WA 501 with a bypass ratio of 2.1. This engine is very small and lightweight; however, high SFC at supersonic cruise results in range values lower than anticipated.

Additional analysis by P&WA indicates that minor changes to the cycle produce significant improvements in performance. Reducing the bypass ratio (BPR) from 2.1 to 1.3 improves the supersonic fuel consumption by reducing the level of duct heating thrust augmentation required for supersonic cruise. However, if conventional primary combustor throttle schedules are employed for this reduced BPR turbofan engine, the primary jet velocity and noise would be excessive during takeoff. Reducing the combustor exit temperature (CET) by approximately 400°F for takeoff reduces the primary stream velocity and the jet noise and provides a better balance in noise between the primary and fan streams. The CET is scheduled to increase to the normal maximum value at end of supersonic climb. P&WA refers to this variable CET feature as the inverse throttle schedule (ITS). There is a slight increase in engine weight due to the larger gas generator size that accompanies the reduced BPR.

The improved DH/TF engine is identified as the P&WA VSCE 502. P&WA provided a data package on the engine (VSCE 502) as part of their NASA-Lewis funded 1974 Advanced Supersonic Propulsion System Technology studies.

Modification to the P&WA supplied data to incorporate the DAC 2.2 M AST installation requirements (inlet airflow schedule, inlet recovery, customer bleed and power extraction) and to correct to standard day conditions have been concurred in by P&WA. This results in an engine unique to DAC, identified as 502D. The engine schematic is identical to that shown in Section 3, Figure 3-5 of the basic report, NASA CR-132610.

ENGINE SIZING

GENERAL ANALYSIS

Sizing criteria for the P&WA 502D engine is takeoff thrust [52,000 lb. (231.3 kN) per engine, uninstalled, suppressed, no external drag], suppressor temperature limit [1200°F mechanical limit (922°K) for chute type and 1500°F material limit (1089°K) for finger type, per P&WA] and FAR Part 36 noise [sea level, 0.3 Mach, 2270 ft. (692 m) sideline and 1050 ft. (320 m), 0.3 Mach, takeoff/cutback, standard + 18°F (10°C) day].

Figure 5-1 illustrates the engine sizing logic based on P&WA suppressor temperature limits, suppressor type and characteristics, engine airflow, and four engine unsuppressed sideline noise (DAC calculations). Data are shown for no suppressor, a chute type suppressor, and a finger type suppressor, as a function of duct heat temperature. P&WA suppressor loss data are used to determine takeoff thrust required (see Figure 3-7 of the basic report). Schematics of the chute and finger suppressor configurations are shown in Figure 3-8 of the basic report. As shown in Figure 5-1, the minimum size suppressed solution is a 918 lb/sec (417 kg/sec) inlet corrected airflow engine providing 54,995 lb. (244.6 kN) of thrust [52,000 lb. (231.3 kN) suppressed] at S.L., 0.3 M, standard + 18°F (10°C) day with a 6.2 PNdB finger type suppressor on the fan stream. Subsequently, P&WA has indicated that the finger type suppressor could be used at exhaust gas temperatures up to 1700°F (1200°K). This would reduce the minimum engine size to 885 lb/sec (402 kg/sec) inlet corrected airflow.

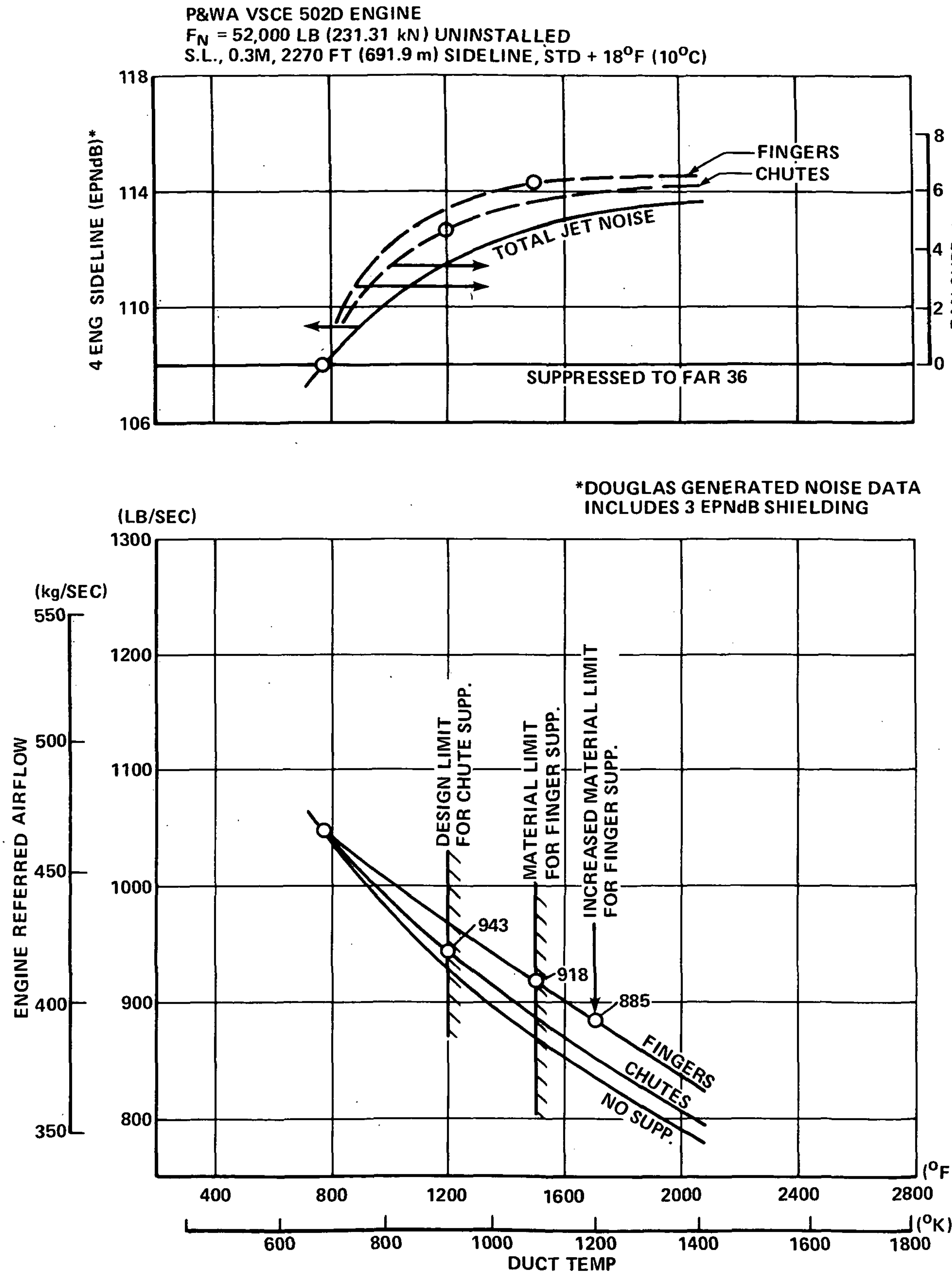


FIGURE 5-1. ENGINE SIZING FOR TAKEOFF

At the takeoff/cutback point, 33,250 lb. (147.9 kN) of thrust, the fan stream velocity is too low to gain benefit from the suppressor. Further, as shown in Figure 5-2, the unsuppressed jet noise is 106.9 to 108.2 EPNdB depending on the aircraft altitude over the 3.5 n.mi. (6.5 km) noise monitor. For this configuration, the altitude at 3.5 n.mi. (6.5 km) is estimated at 1260 ft. (386 m). This results in a noise value of 107.2 EPNdB, and importantly, the suppressor is stowed at and beyond this point.

Before selecting an engine size based on mechanical suppressor constraints, an evaluation was made of the coannular suppression effect being tested and reported by P&WA and to determine its impact on engine sizing. Based on P&WA data, the coannular effect reduces the jet noise at sideline by 9 PNdB and at takeoff/cutback by 6 PNdB. This includes the contribution of a lined ejector. Figure 5-3 illustrates the engine sizing logic based on duct temperature, engine airflow, coannular suppression effect and four engine unsuppressed sideline noise (DAC calculations) for the sideline condition. Data are shown as a function of duct temperature. As shown in the figure, the engine can be sized at maximum power with no cutback. The resultant minimum size solution is a 725 lb/sec (329 kg/sec) inlet corrected airflow engine providing 52,000 lb. (231.2 kN) of thrust at sea level, 0.3 M, standard + 18°F (10°C) day with no suppressor. The sideline jet noise at takeoff is 104.7 EPNdB, which is below the FAR Part 36 limit.

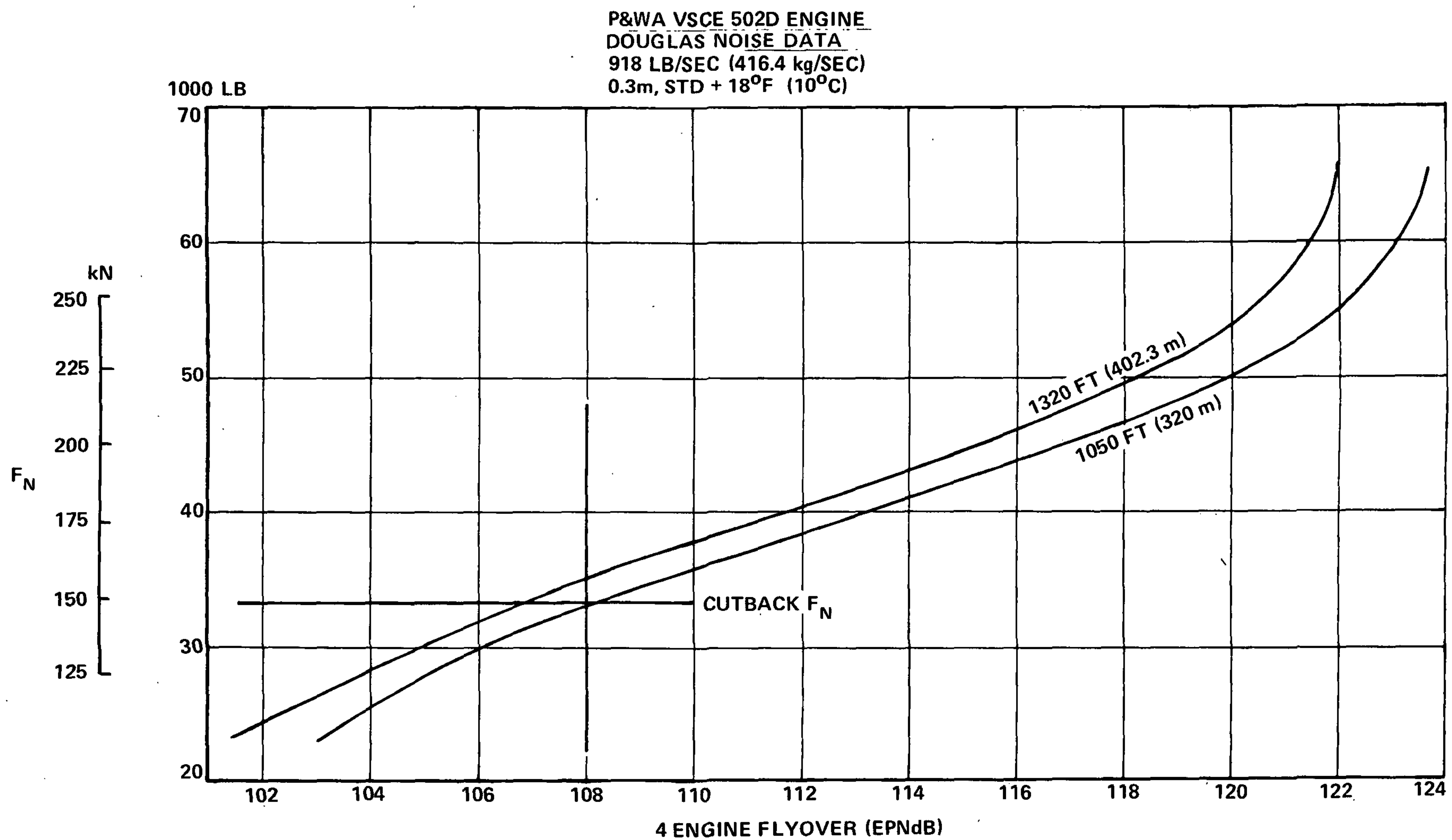


FIGURE 5-2. IN-FLIGHT NOISE CHARACTERISTICS

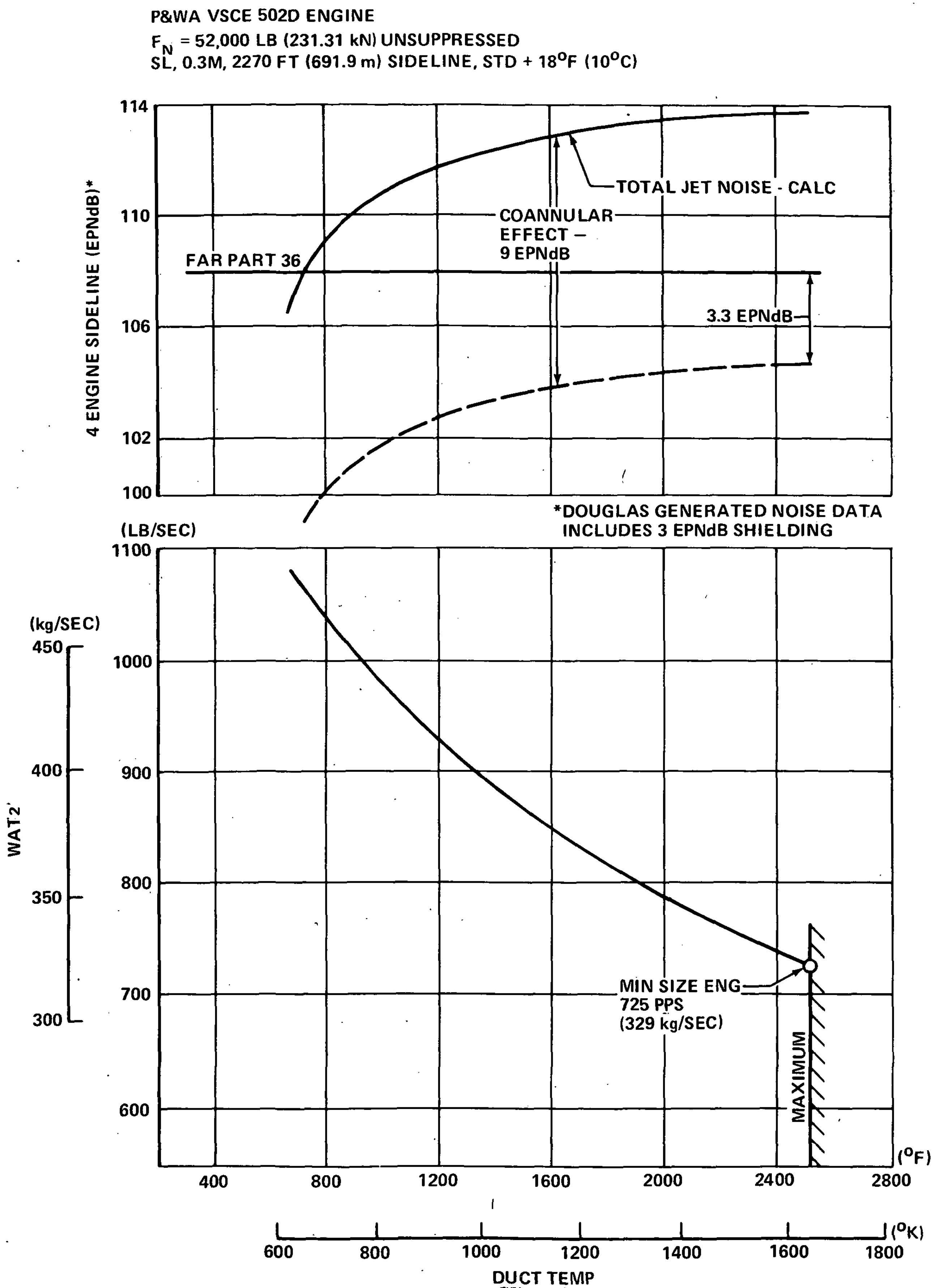


FIGURE 5-3. ENGINE SIZING FOR TAKEOFF

Figure 5-4 illustrates the takeoff/cutback condition for two altitudes over the monitor position. Unsuppressed four engine jet noise and the reduction due to the coannular effect are shown. The unsuppressed jet noise at takeoff/cutback is 111.9 to 113.5 EPNdB depending on the aircraft altitude over the 3.5 n.mi. (6.5 km) noise monitor. For this configuration, the altitude at 3.5 n.mi. (6.5 km) is estimated at 1260 ft. (386 m). This results in a noise value of 112.3 EPNdB. With a reduction of 6 PNdB due to the coannular effect, the jet noise at takeoff/cutback is 106.3 EPNdB, well below the FAR Part 36 limit. With P&WA concurrence, the engine configured with the coannular suppression nozzle is the engine arrangement selected for this study. Therefore, the recommended engine size is 725 lb/sec (329 kg/sec) engine inlet corrected airflow with the coannular suppression nozzle, meeting takeoff thrust requirements while maintaining noise levels at sideline and cutback below the FAR Part 36 limits.

Engine Definition

The engine is a P&WA twin spool duct heating turbofan, which is designed for Mach 2.2 supersonic cruise operation and incorporates 1980 technology (Figure 3-5 of the basic report). It incorporates a DAC designed 2.2 Mach, external compression inlet which is sized for an engine inlet corrected airflow of 725 lb/sec (329 kg/sec) at takeoff rating for sea level static, standard + 18°F (10°C) day. The design cycle characteristics and ratings are shown in Table 5-1.

The nozzle for this engine is a variable area type (variable throat and exit areas) containing an integral thrust reverser and ejector. Both the primary and fan duct throat areas are variable. In an actual design, a fixed primary

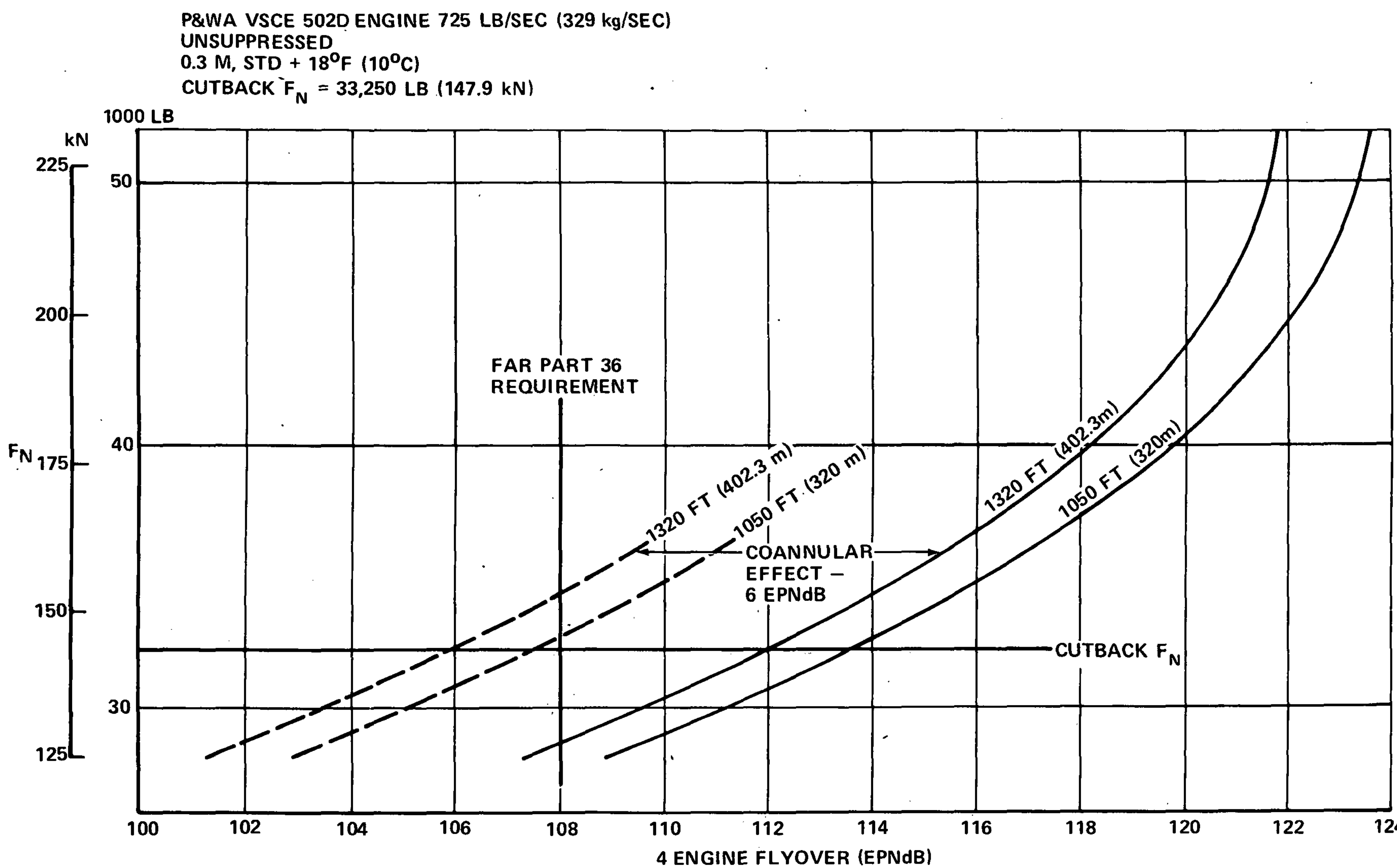


FIGURE 5-4. IN-FLIGHT NOISE CHARACTERISTICS

TABLE 5-1
P&WA VSCE 502D ENGINE CHARACTERISTICS SUMMARY
725 LB/SEC (329 kg/SEC) RATED AIRFLOW

DESIGN CYCLE CHARACTERISTICS

BYPASS RATIO	1.3
FAN PRESSURE RATIO	3.3
CYCLE PRESSURE RATIO	15.0
COMBUSTOR EXIT TEMP	2300°F (1533°K) [T.O., STD + 18°F (10°C)]
	2600°F (1700°K) [SUPERSONIC CLIMB STD + 14°F (8° C)]

TAKEOFF RATINGS [STD DAY + 18°F (10°C)]

MAX THRUST (SLS) - LB (kN)	53,773 (239.19)
MAX THRUST (SL, 0.3 M, UNINSTALLED) - LB (kN)	52,000 (231.31)

WEIGHT

ENGINE - LB (kg)	7,624 (3458.2)
ENGINE/NOZZLE/REVERSER - LB (kg)	9,836 (4461.6)

DIMENSIONS

ENGINE INLET GAS FLOW PATH DIAMETER - IN. (m)	66.5 (1.689)
HUB-TO-TIP RATIO (AT PLANE OF ATTACH FLANGE)	.284
ENGINE MAX DIAMETER - IN. (m)	79.0 (2.007)
LENGTH - INLET FLANGE TO EXHAUST PLANE - IN. (m)	228.3 (5.809)

SCALING FACTORS

WEIGHT $\frac{WT}{WT\ BASE} = \left(\frac{WAT2}{725}\right)^{1.073}$

DIAMETER $\frac{D}{D\ BASE} = \left(\frac{WAT2}{725}\right)^{0.50}$

LENGTH $\frac{L}{L\ BASE} = \left(\frac{WAT2}{725}\right)^{0.44}$

COST*

WITHOUT SUPPRESSOR $2.72M

SCALING FACTOR $\frac{COST}{COST\ BASE} = \left(\frac{WAT2}{725}\right)^{0.53}$

*BASED ON:
- 1973 DOLLARS
- 1980 ENGINE TECHNOLOGY
- PRICES INCLUDE ALL DEVELOPMENT COSTS PLUS FIVE-YEAR PRODUCT SUPPORT AFTER CERTIFICATION, BASED ON ONE-ENGINE MODEL
- 3000-ENGINE PRODUCTION RUN

nozzle would probably be desired for design simplicity. It is assumed by P&WA that the engine cycle could be tailored to produce equivalent performance with a fixed primary exhaust control nozzle. P&WA recommended an exhaust system similar to the chute type exhaust system (without the chute suppressor) shown in Figure 3-8 of the basic report to take advantage of the additional suppression from the lined ejector. Design layouts revealed that this type exhaust system would not allow canting of the exhaust due to the length of the straight forward translating section. Therefore, an evaluation was made of alternate exhaust system schemes, provided by P&WA per DAC request. On the basis of size, weight and installation compatibility of the various exhaust systems, a mixer type exhaust system with blow-in doors (equivalent to the finger type exhaust system, without the finger suppressor, shown in Figure 3-8 of the basic report) has been selected as the baseline configuration for this engine. The base engine, including the P&WA nozzle, is described in Figure 5-5. The installed engine/nacelle arrangement is shown in Figure 5-6.

Engine weights, dimensions, scaling equations and cost data are presented in Table 5-1. The cost data are based on P&WA cost information provided as part of their Advanced Supersonic Propulsion System Technology Studies conducted under contract to NASA Lewis in 1973. Costs have been escalated to 1973 by DAC based on 1972 dollar values provided by the engine manufacturer's study.

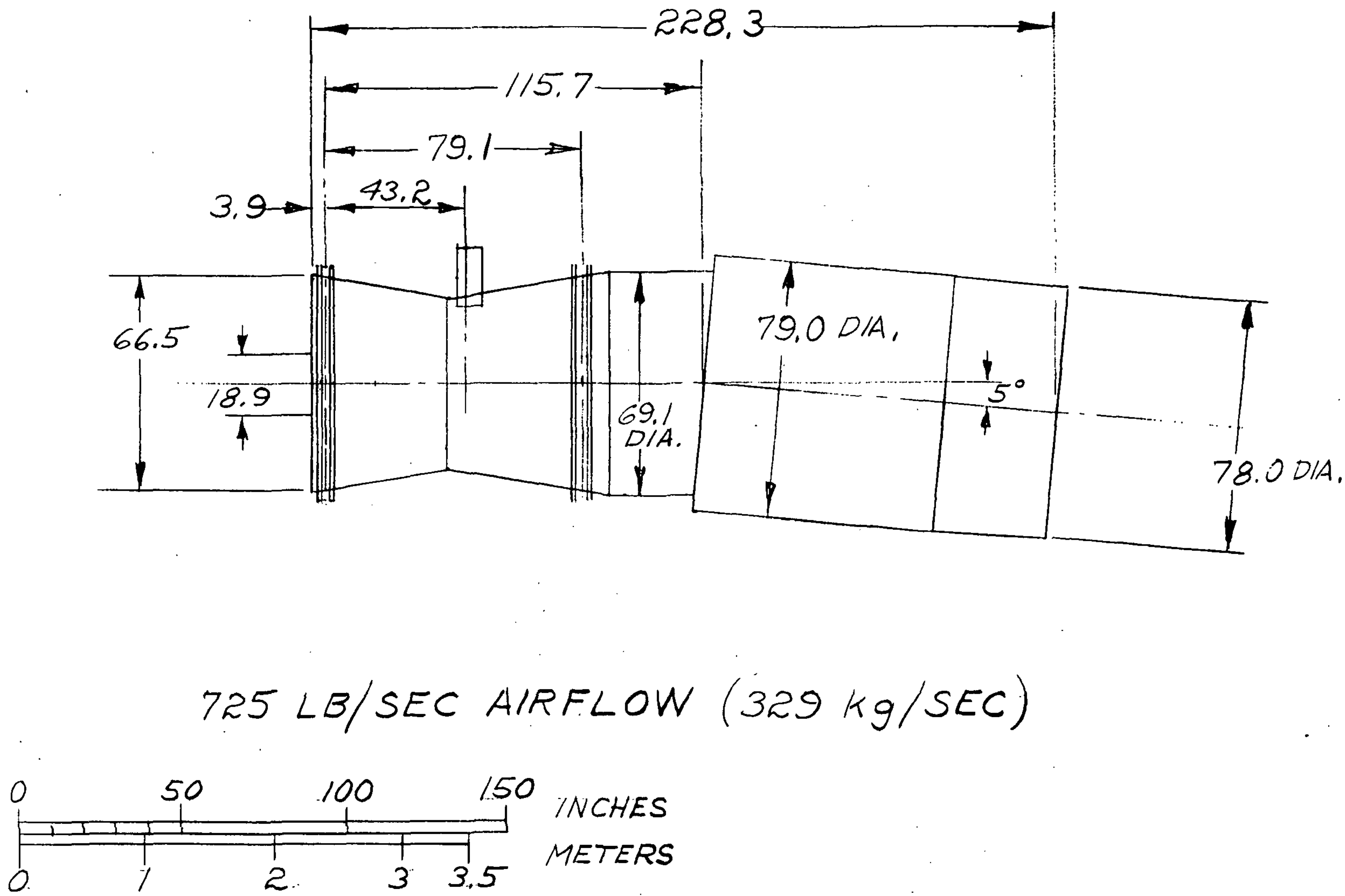


FIGURE 5-5. P&WA VSCE 502D ENGINE

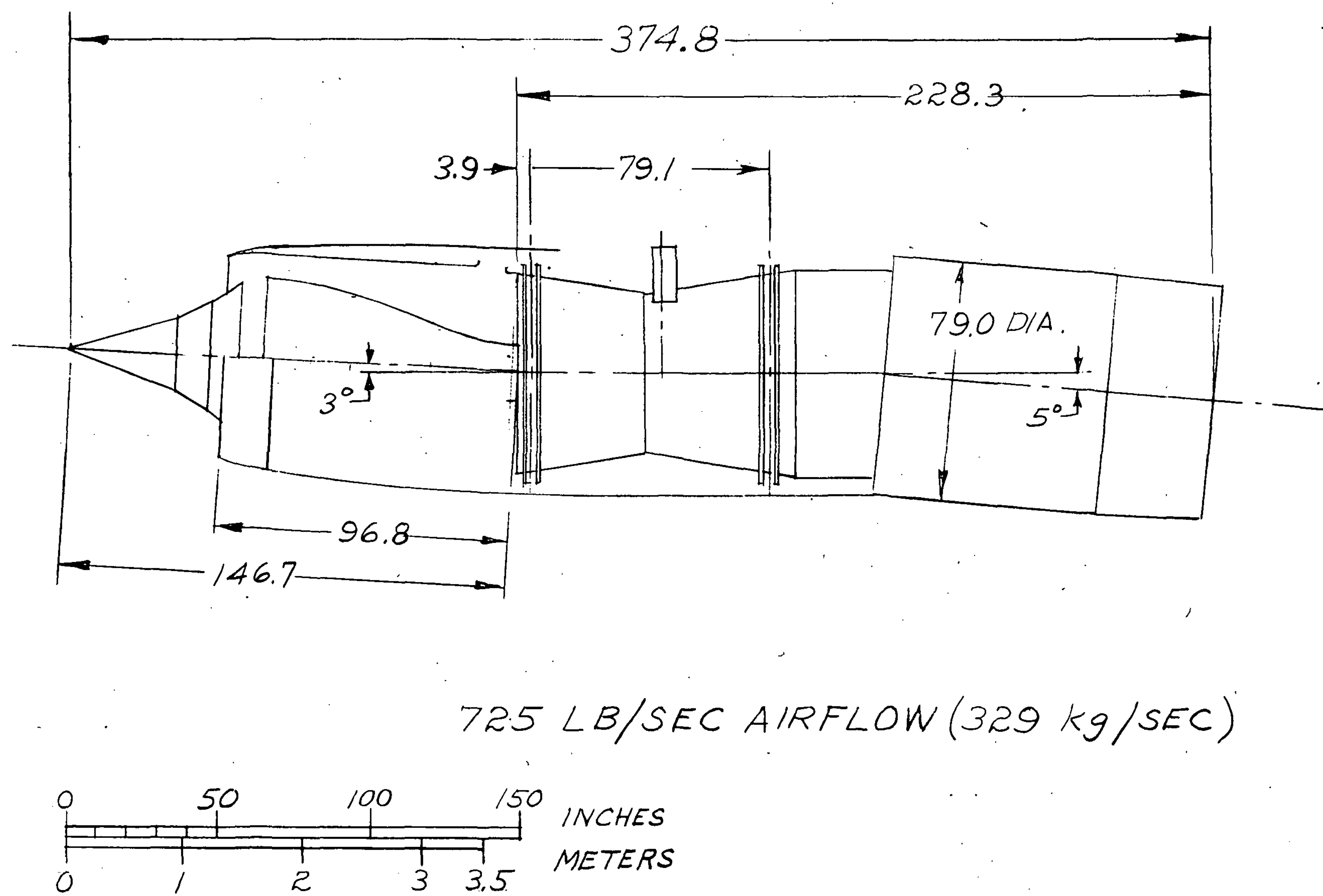


FIGURE 5-6. P&WA VSCE 502D ENGINE INSTL

PROPULSION SYSTEM PERFORMANCE

Uninstalled Performance

The uninstalled performance data are obtained by correcting the P&WA supplied data package as required to include the effects of:

o	U.S. 1962 model atmosphere	
o	Inlet recovery	Figure 1-6 (Basic Report)
o	P&WA supplied internal nozzle velocity coefficient	
o	Customer compressor air bleed	1 lb/sec (.454 kg/sec)
o	Customer power extraction	200 HP (149 kW)
o	Jet A Fuel, Lower Heating Value	18,400 BTU/lb (4.34×10^7 J/kg)
o	No losses for acoustic treatment	

Installed Performance Analysis

The analysis of the propulsion system performance of the VSCE 502D engine follows the same procedures used for the baseline turbojet engine (Section 1 of the basic report).

The inlet performance and the nacelle analysis include an evaluation of the following items:

- Inlet spillage drag
- Inlet bypass drag
- Engine and ECS cooling airflow drag
- Nacelle skin friction drag
- Nacelle afterbody drag
- Nacelle wave drag

The inlet geometry and cone schedules are the same as used for the turbojet engine. The inlet total pressure recovery variation is shown in Figure 1-6 of the basic report. Also shown in the figure is the variation of inlet critical mass-flow ratio. Shown in Figure 1-7 of the basic report is the mass-flow ratio for the inlet boundary layer bleed airflow.

The engine airflow schedule for the VSCE 502D engine is the same as for the baseline turbojet (Figure 1-8 of the basic report). The installed inlet performance for the VSCE 502D engine is shown in Figure 5-7. As shown by the upper graph in the figure, the inlet airflow supply provides an adequate match with the engine airflow demand. The inlet is sized at the design point of 2.2 M. The sized capture area is 22.33 ft.^{2} (2.07 m^2). The engine cooling airflow (environmental cooling and engine compartment ventilation) is estimated at 2 percent of inlet capture air at Mach 2.2 cruise. Figure 5-7 presents the estimated performance loss per engine for this cooling air. The cooling air passes through the nacelle and is then expanded overboard through a flush sonic nozzle, thus recovering part of the ram drag. It is assumed that the total pressure of the cooling air at the nozzle is equal to 40 percent of the inlet total pressure at the higher flight Mach numbers. At flight conditions below Mach 1.5, it is assumed that engine bleed air is used to pump the cooling air and no thrust augmentation benefit is realized.

The nacelle drag-coefficient buildup is shown in the lower graph in Figure 5-7. The inlet drag characteristics are calculated by combining the mass-flow ratio characteristics with empirical drag coefficient correlations. For the convenience of engine sizing studies, the nacelle skin friction drag is included

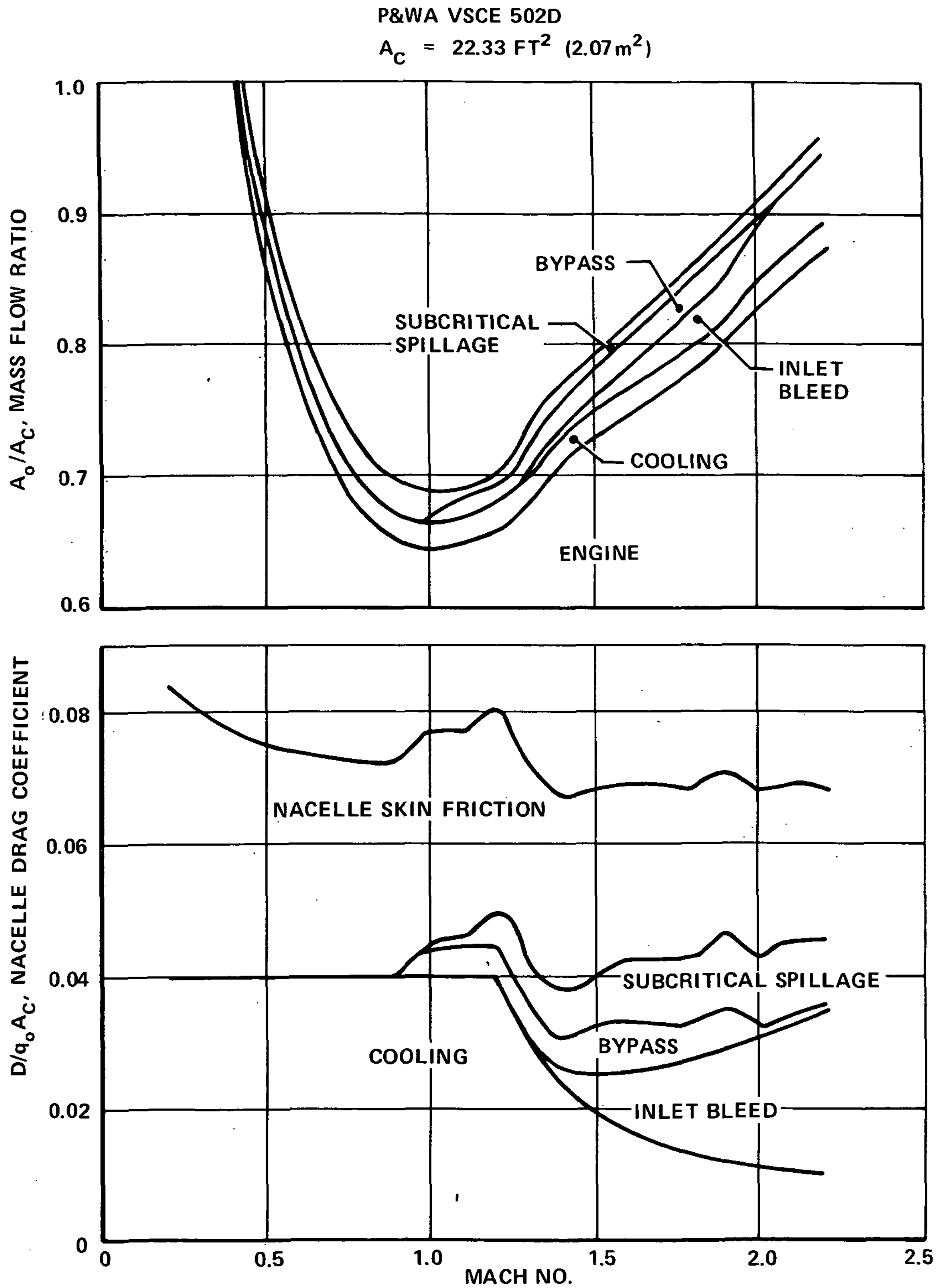


FIGURE 5-7. INSTALLED INLET PERFORMANCE

in the installed engine performance. The skin friction coefficients are based on fully turbulent flat plate adiabatic wall boundary layer data with transition at the leading edge. The resulting drag is shown in Figure 5-7.

The nacelle afterbody drag is dependent on the nozzle exit area and flight Mach number. The maximum nozzle area is sized at 2.2 M climb at maximum augmentation. The engine dependent boattail drag at this condition is zero. As nozzle area decreases for lower Mach numbers, and reduced power settings, the boattail drag increases. The boattail drag identified with this area change is based on drag characteristics estimated for the DAC baseline ejector nozzle configuration. The variation in drag coefficient relative to the design cruise drag along the aircraft climb path as a function of climb thrust and for subsonic flight is shown in Figures 5-8 and 5-9.

The nacelle wave drag in the presence of the aircraft, including the supercritical spillage drag and the design afterbody drag, is part of the aircraft wave drag.

Performance Results

Installed propulsion system performance is generated by correcting the uninstalled engine performance data for the installation effects described above. The climb performance characteristics are generated along the aircraft flight path shown earlier in Figure 1-12 of the basic report. Uninstalled and installed thrust for the maximum takeoff power setting (with maximum augmentation) are shown in Figure 5-10. Figures 5-11 and 5-12 show the uninstalled and installed thrust and SFC, respectively, for maximum climb thrust along the climb flight path. Uninstalled and installed supersonic cruise, subsonic cruise (for alternate

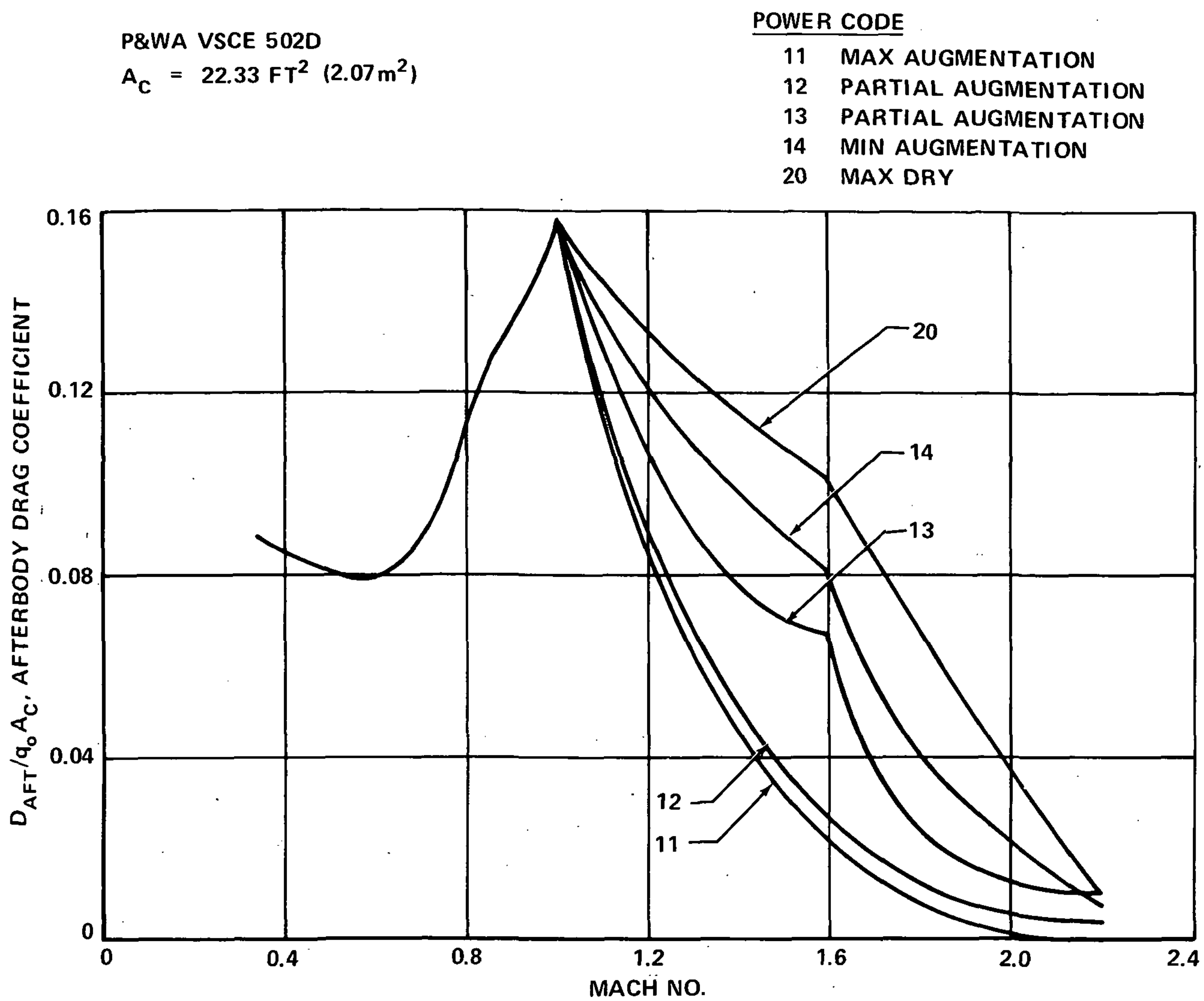


FIGURE 5-8. CLIMB AFTERBODY DRAG

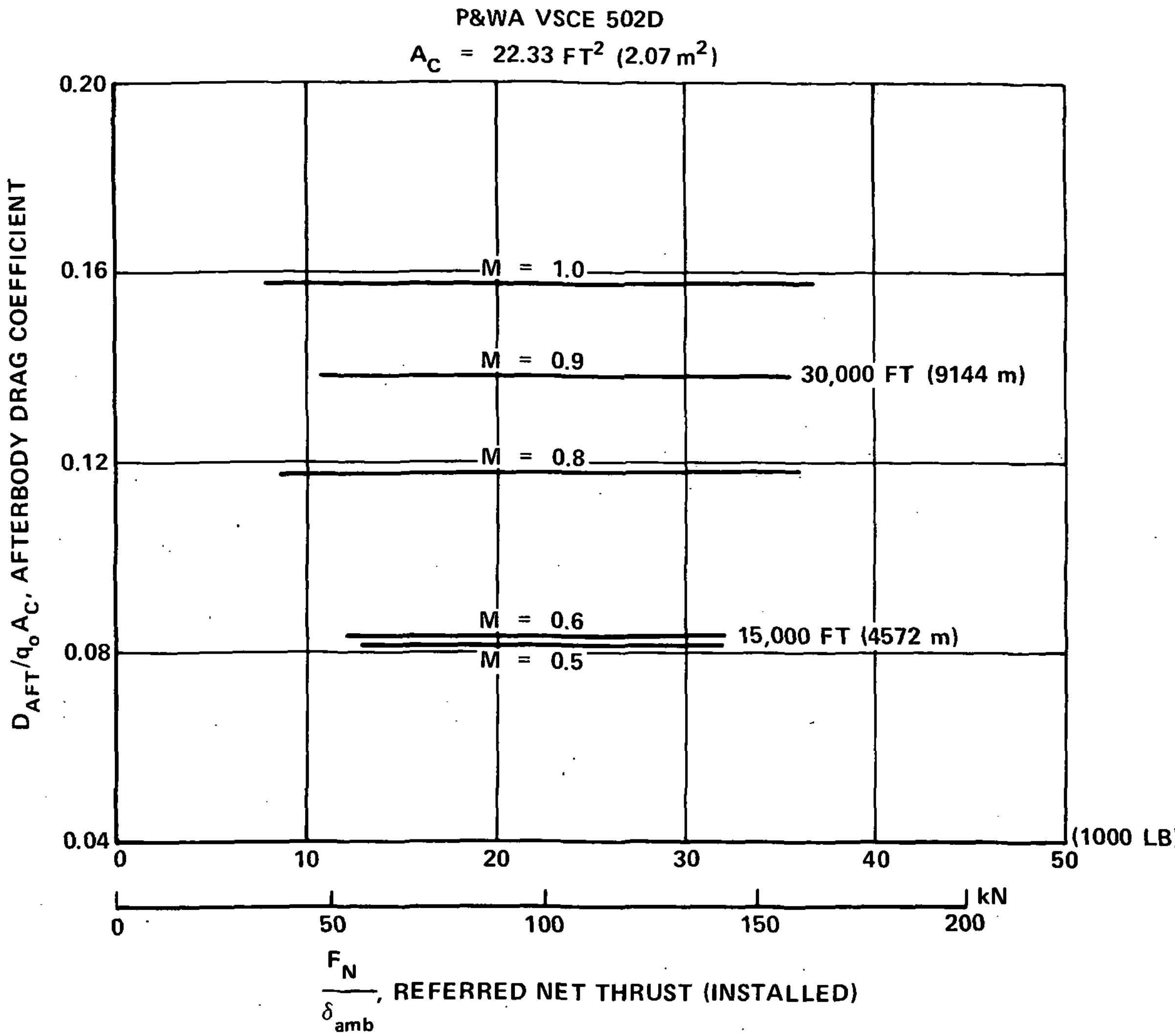


FIGURE 5-9. SUBSONIC AFTERBODY DRAG

P&WA VSCE 502D
SEA LEVEL, STD + 18°F (10°C) DAY
WAT2 = 725 LB/SEC (329 kg/SEC)
T_{DUCT} = 2515°F (1653°K) AT 0.3M
SLS RATING = 53,773 LB (239.2 kN)
100% SLS THRUST (UNINSTALLED) = 49,846 LB (221.8 kN)

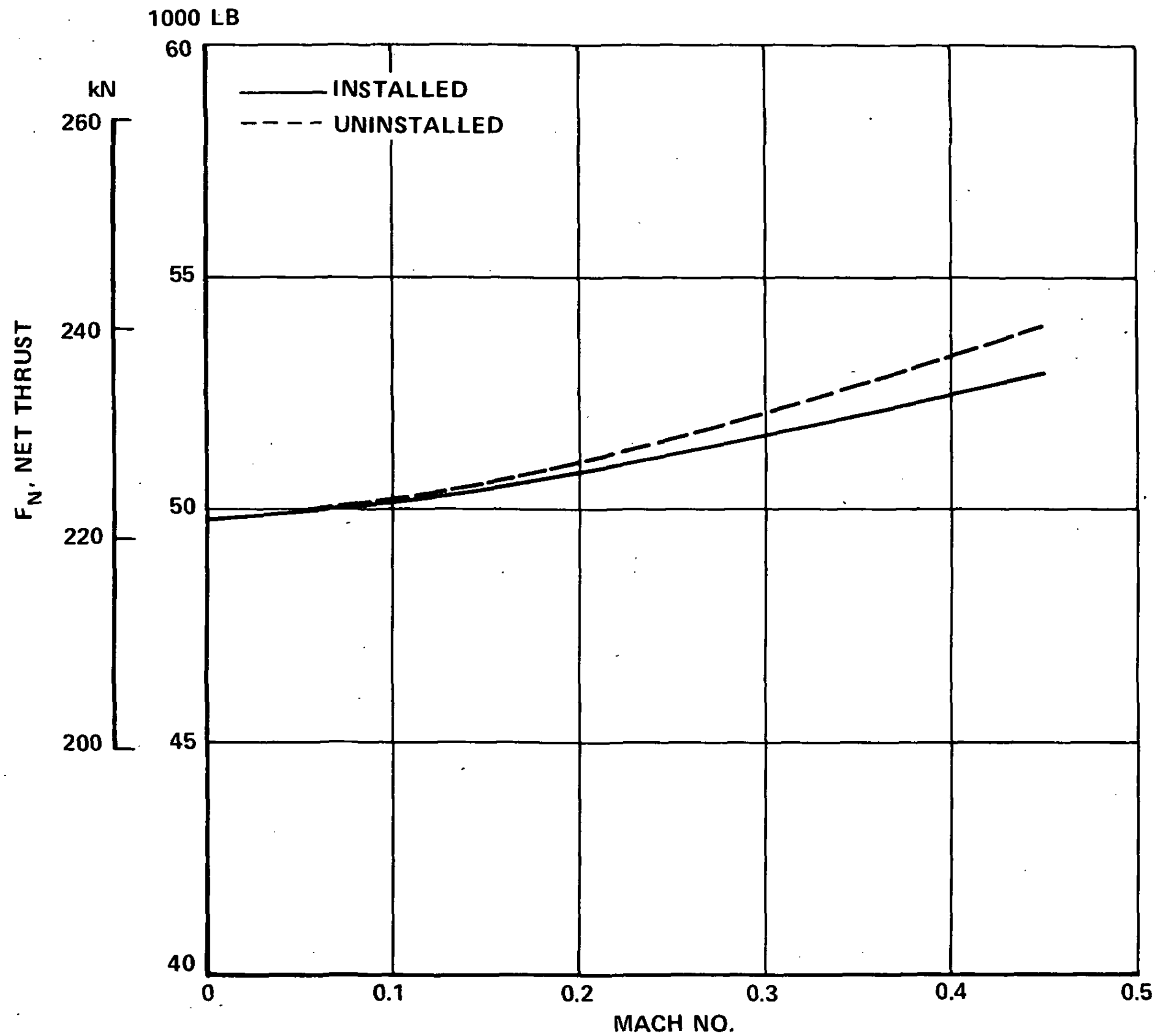


FIGURE 5-10. TAKEOFF PERFORMANCE

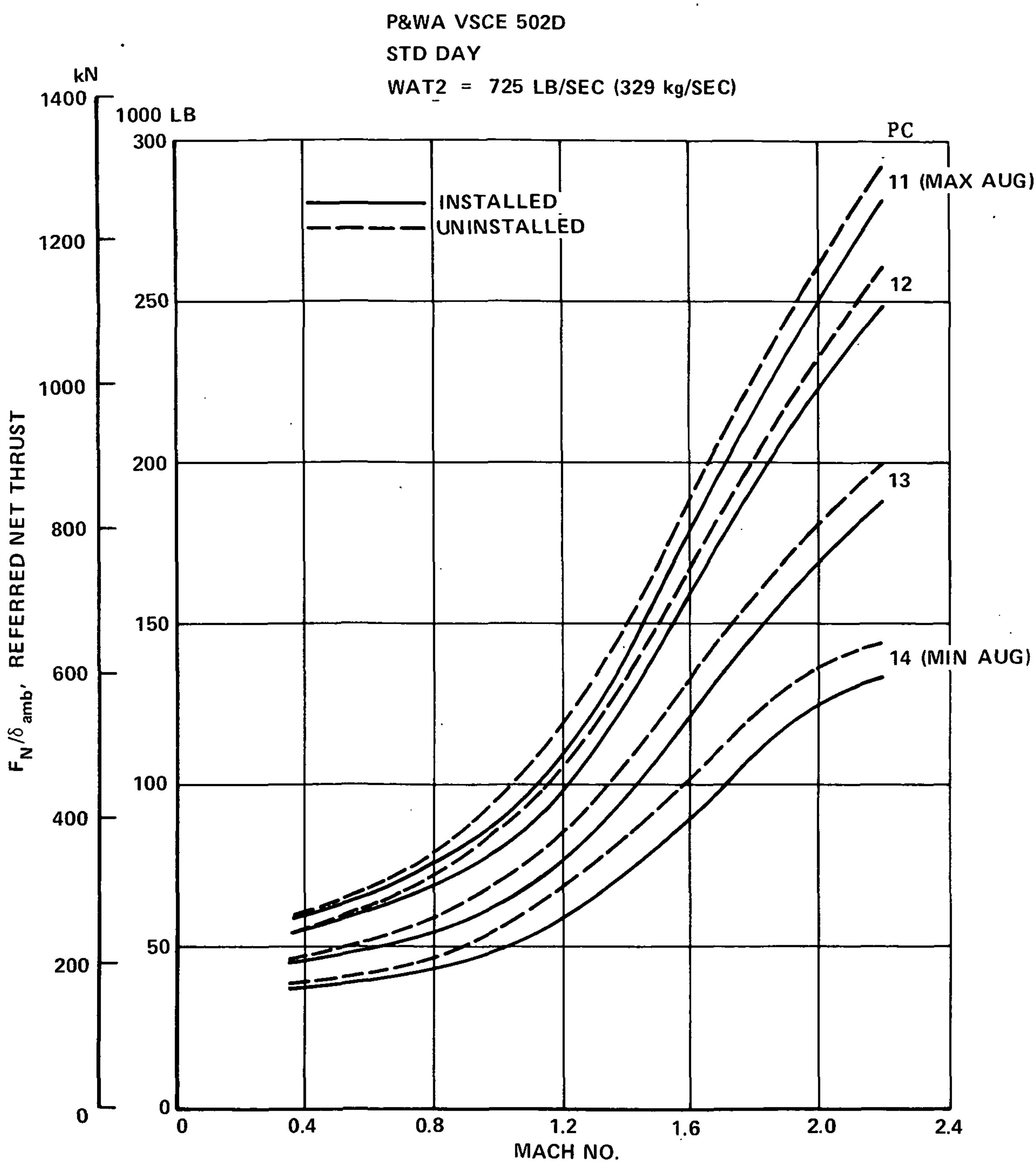


FIGURE 5-11. CLIMB THRUST

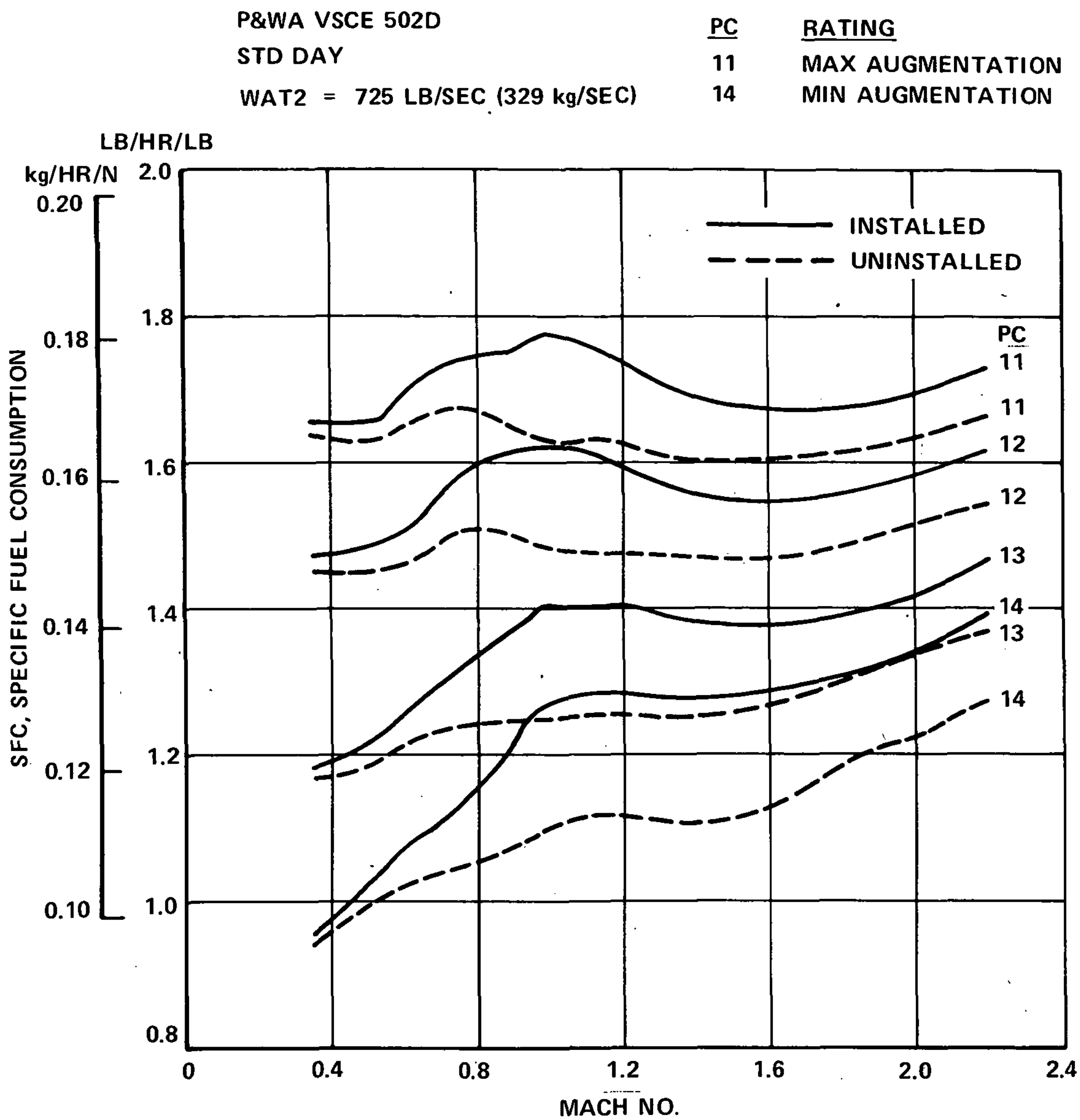


FIGURE 5-12. CLIMB SFC

mission), and hold performance are shown in Figures 5-13 through 5-15. Note that the afterbody drag associated with subsonic cruise results in a significant installation penalty (see Figure 5-15). Figure 5-16 presents the installed idle performance characteristics used along the descent flight path.

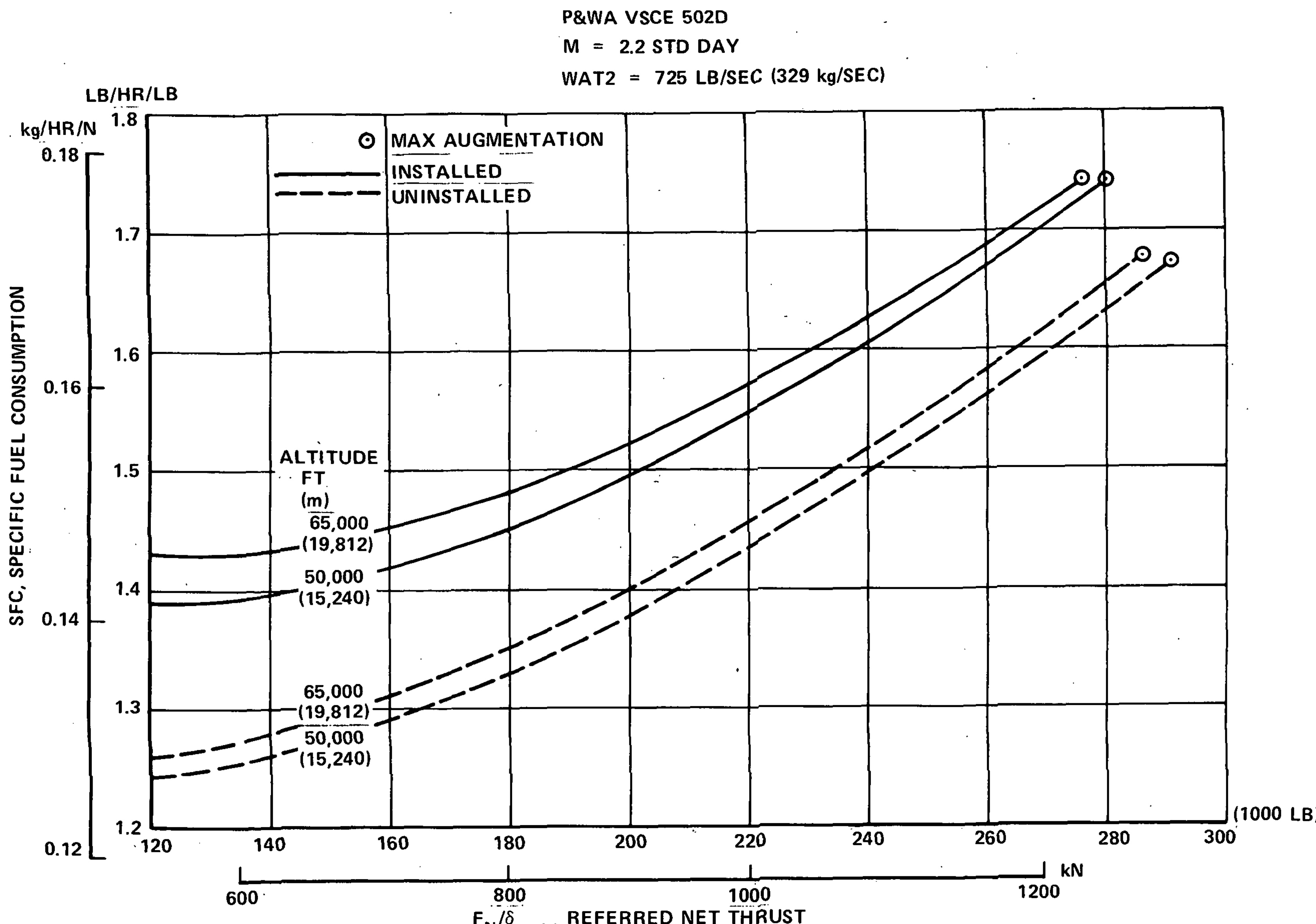


FIGURE 5-13. SUPERSONIC CRUISE PERFORMANCE

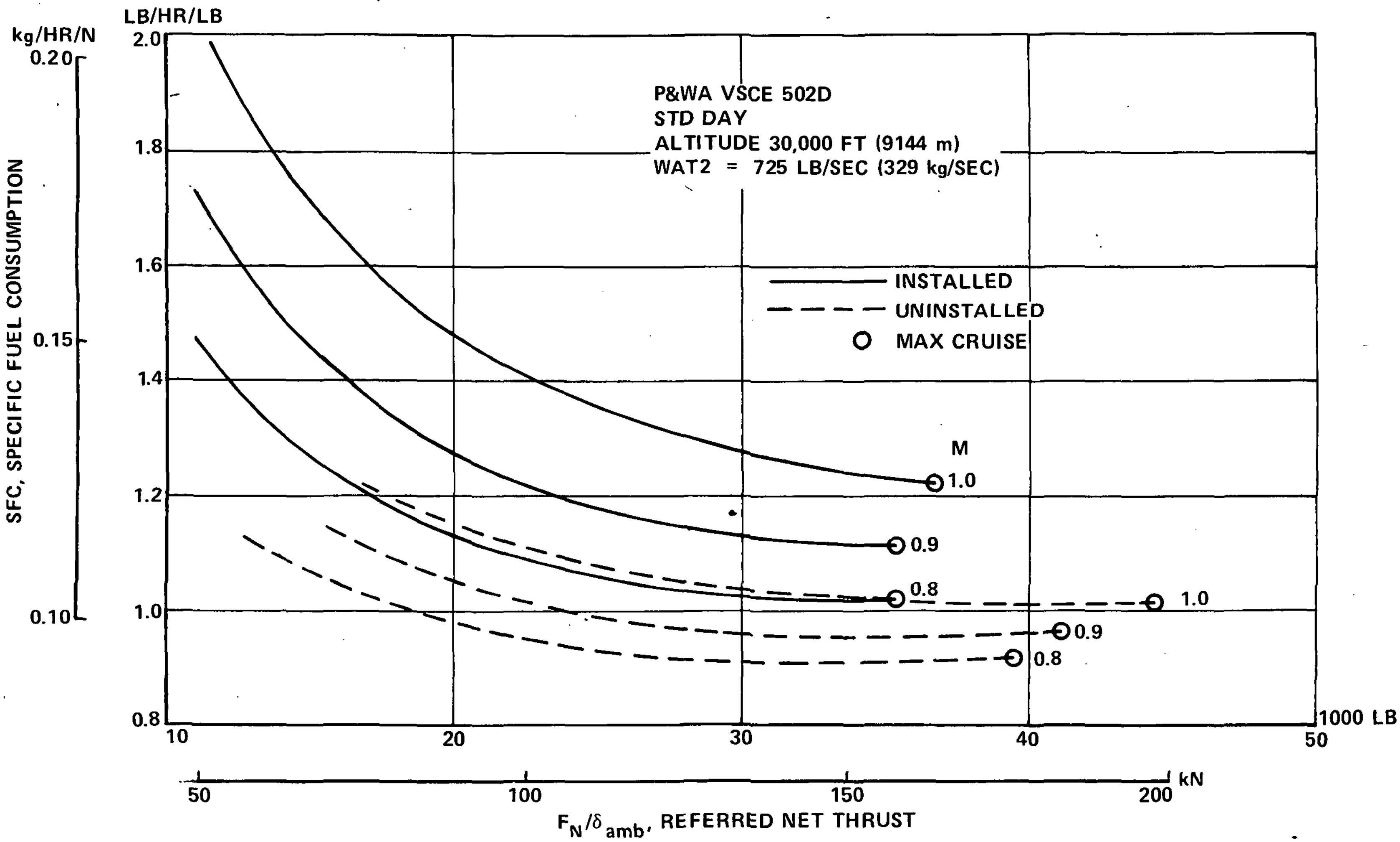


FIGURE 5-14 SUBSONIC CRUISE PERFORMANCE

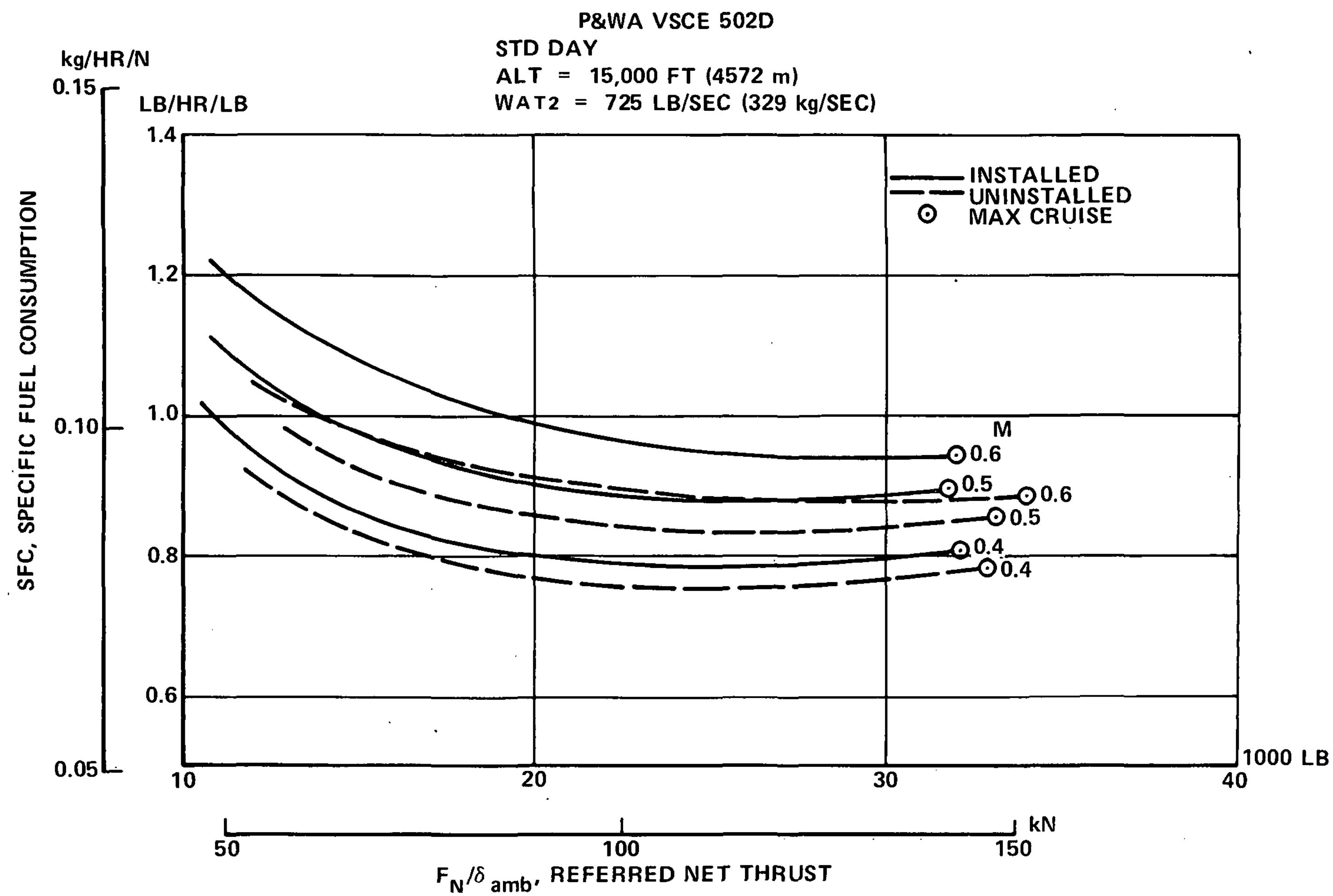


FIGURE 5-15. LOITER PERFORMANCE

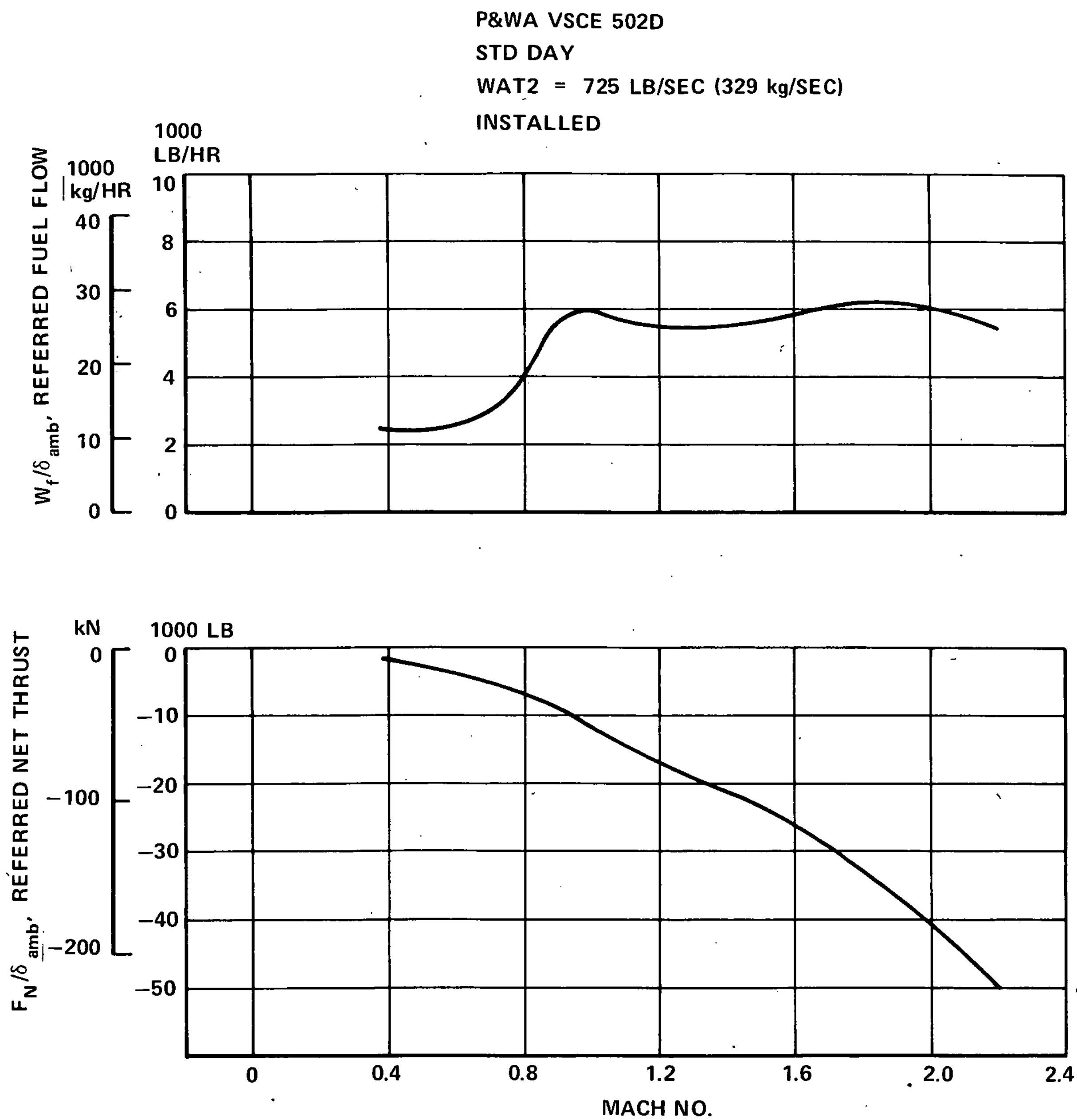


FIGURE 5-16. IDLE PERFORMANCE

Engine/Nacelle Location

Installation studies of the VSCE 502D engines in four axisymmetric nacelles for the baseline airframe have been completed. Inboard and outboard spanwise locations remain as for the -5A baseline configuration to maintain existing wing torque box structure, location of control surfaces, and overall area distribution equivalent to the baseline configuration. The choice of the forward and aft location has been determined analytically from the inputs from aerodynamics, structural mechanics, acoustics, and power plant. The inlet on the inboard nacelle is located 13 inches (33 cm) aft and the outboard inlet is 30 inches (76 cm) aft with respect to the baseline configuration.

With the resultant location of engines on the wing, use of the full circumferential openings for thrust reversing proposed by the engine manufacturer cannot be utilized. Thrust reversing is only achievable in local areas (90°) above and (120°) beneath the wing surfaces to clear the deployed aircraft flap system (Figure 5-17).

The locations as shown on the three view drawing provide the best solution to the requirements of the previously established criteria (Figure 5-18). This configuration is hereafter referred to as the -5G.

Engine/Nacelle Attachment on the Wing

The engine is mounted on the wing by a three point attachment to the wing structure. The aft mount is attached to a box beam pylon cantilevered aft of the rear spar and the two forward mounts are attached to structure provided on the wing box off the rear spar. The forward right-hand mount carries thrust loads, vertical loads and side loads. The left-hand forward mount transmits

forward and vertical loads only. The rear engine mount carries vertical loads and translates for engine growth under operating temperatures (Figure 5-17).

The axisymmetric intakes are mounted to the engine casing and divorced from the wing structure. This eliminates transmission of wing deflection loads to the intake preventing distortion of the intake geometry and loading of the engine casing. The boundary layer diverter is integrated into the engine nacelle/wing fairing.

The installed weight of the VSCE 502D is the lightest weight of the study engines evaluated to date, including the baseline turbojet engine, which results in significant weight savings in airframe structures.

<u>Other Configuration Changes</u>

The reduced size and length of the installed engine pods for the 502D engines enables the use of a 23 inch (58 cm) shorter landing gear and a reduced tail bumper fairing. The ground clearance limit becomes fixed by the tail bumper and not the length of the pods.

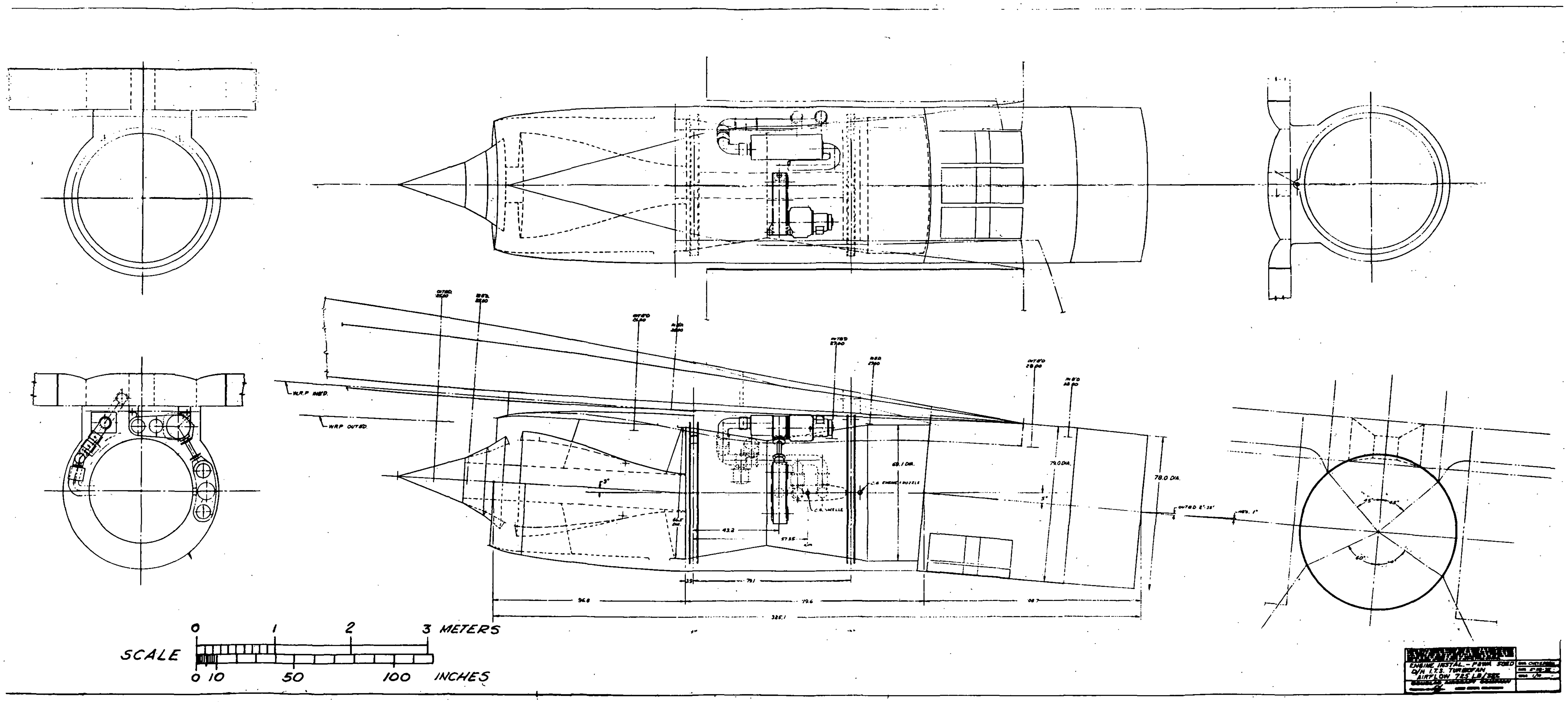


FIGURE 5-17. P&WA VSCE 502D ENGINE INSTALLATION SCHEMATIC

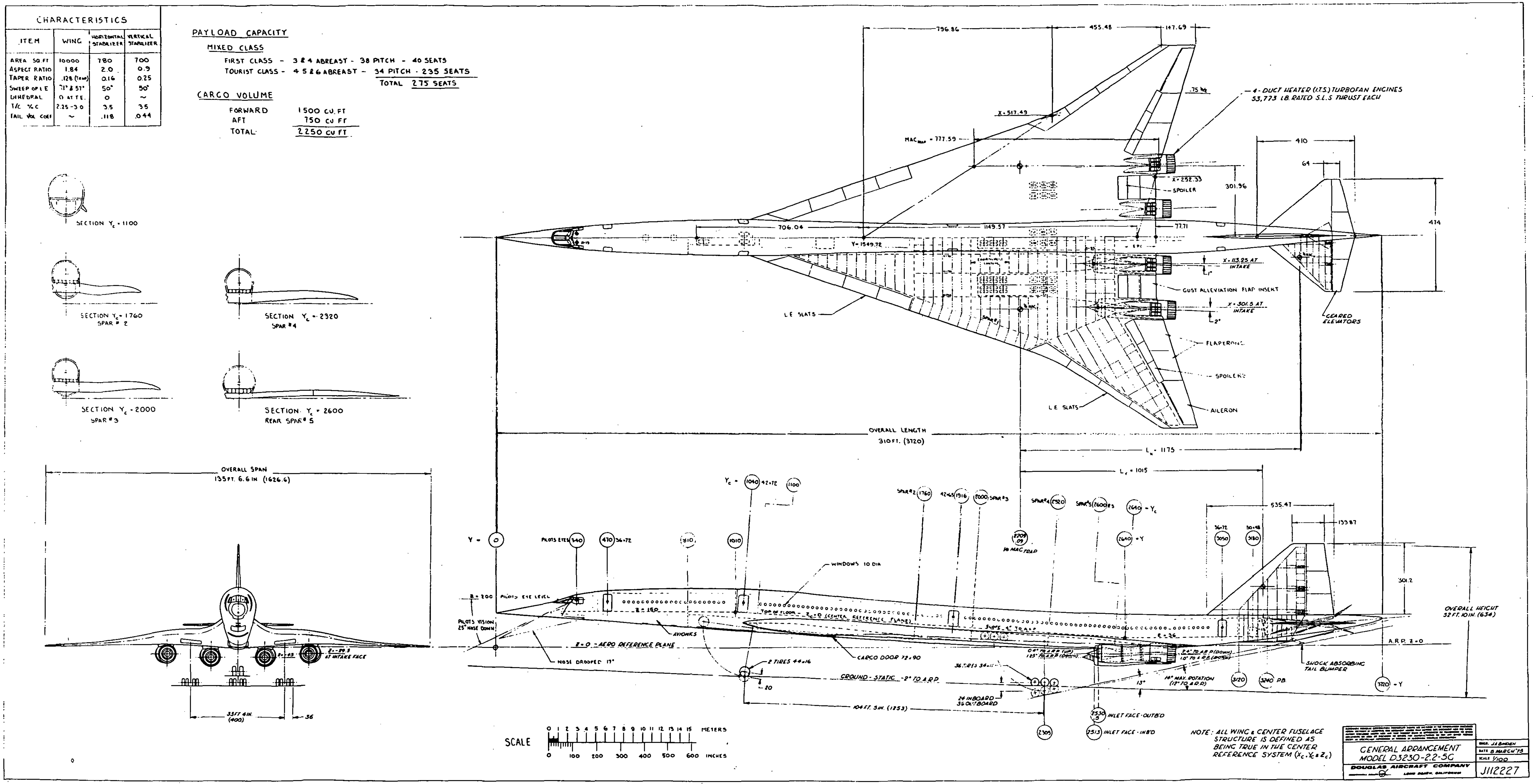


FIGURE 5-18. P&WA VSCE 502D ENGINE CONFIGURATION

ACOUSTIC ANALYSIS

The acoustic analysis, conducted for the aircraft configuration powered by the P&WA VSCE 502D engine, consists of the calculation of estimated jet noise in support of engine sizing studies. Engine data have been employed to estimate the jet noise at aircraft Mach numbers and altitudes representative of the FAR Part 36 takeoff and sideline measuring conditions. After the engine size has been determined, the flight path for the variable stream control engine powered aircraft configuration is calculated and engine cycle data at the above two conditions defined. The noise levels for the two conditions are then estimated using the DAC gas turbine engine noise (GTEN) computer program. The standard climb profile incorporates a thrust cutback over the takeoff measuring station.

The engine size has been selected at an airflow rate of 725 lb/sec (329 kg/sec). The jet noise suppression required is provided by coannular nozzles as reported by P&WA and is 9 PNdB at the sideline and 6 PNdB at the takeoff measuring points, respectively. Descriptions of the engine sizing results are given in the Engine Sizing Section.

The unsuppressed jet noise levels for the 725 lb/sec (329 kg/sec) VSCE 502D engine in the baseline airplane based on specific engine conditions for the calculated takeoff trajectory are as follows:

FAR PART 36 MEASURING STATION	DISTANCE, FT.(m)	UNSUPPRESSED TOTAL NOISE EPNL, EPNdB
Sideline	2270 (692)	116.7*
Takeoff/Cutback	1230 (375)	112.5

*Includes no allowance for extra ground attenuation or shielding

The suppressed noise levels for this configuration are described in the Engine Selection Section.

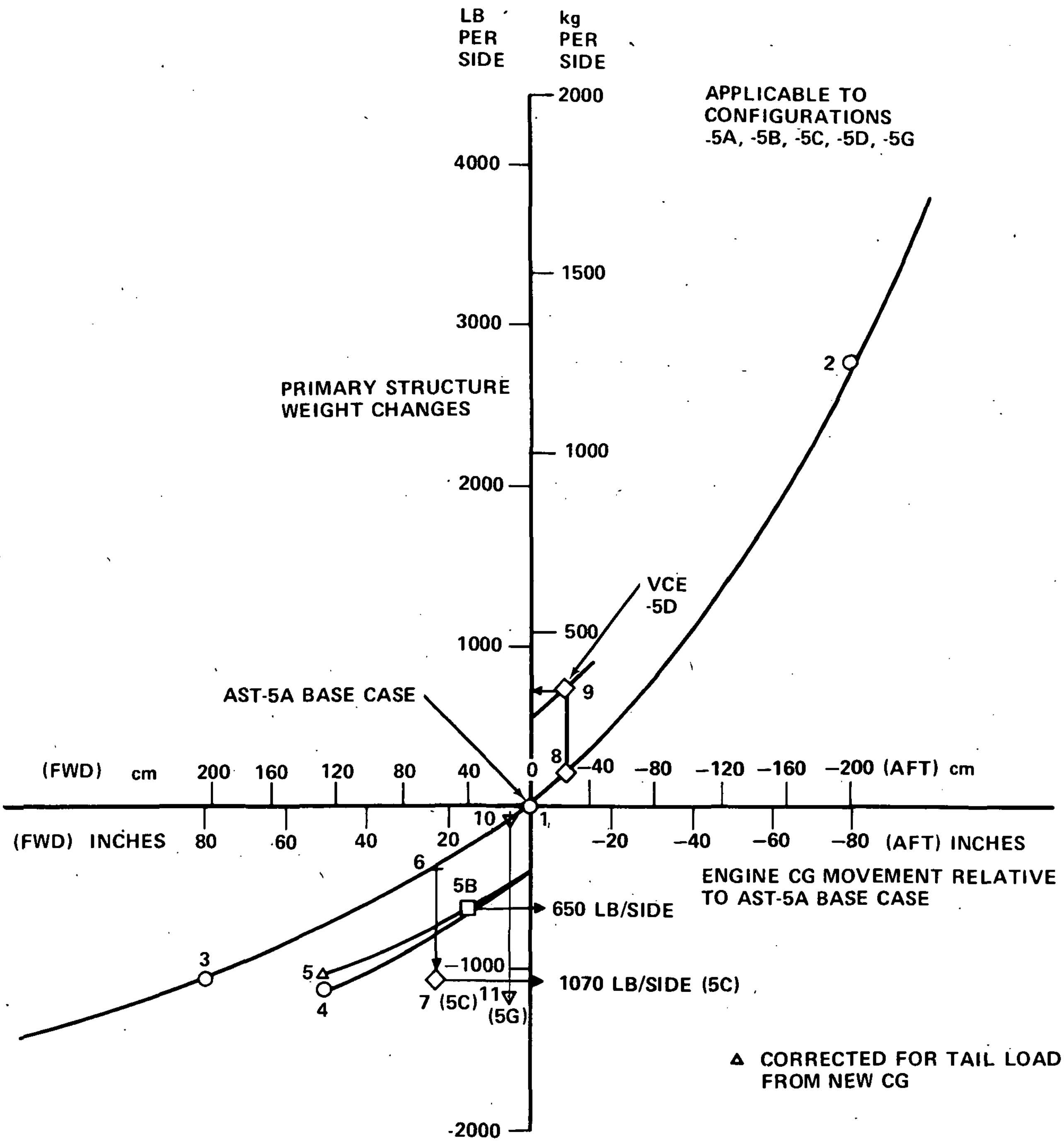
STRUCTURAL ANALYSIS

Strength Analysis

The VSCE 502D engine propulsion system plus nacelle weight from Table 5-2 is 54,769 lb (24,843 kg). This compares to 84,920 lb (38,519 kg) for the baseline -5A. Therefore, the weight reduction is 15,075 lb (6850 kg) per side. The saving in structural weight for this decrease in propulsion weight is 1110 lb (505 kg) per side (point 11 minus point 10 in Figure 5-19). The 5.0 inch (13 cm) more forward location for the variable stream control engine c.g. results in an additional 80 lb (36 kg) per side structural weight saving (point 10 in Figure 5-19). This totals 1190 lb (541 kg) per side or 2380 lb (1082 kg) structural weight saving per airplane.

Flutter Analysis

A flutter analysis of the VSCE 502D engine configuration (-5G) reveals that its reduced weight results in a lower flutter speed than the lightest weight configuration considered in previous analysis (see Section 4, page 4-52 of the basic report). The weight increment required to maintain the flutter speed of 480 KEAS (247 m/sec EAS) is estimated to be 1173 lb (575 kg). This allocation might be reduced slightly by use of the detailed flutter optimization program to obtain the optimum specific weight distribution; however, it is anticipated that this improvement will be minor. This 1173 lb (575 kg) is added to the 2000 lb (907 kg) for aeroelasticity to make a total of 3173 lb (1439 kg) which is included in the weight statement for the -5G configuration (Table 5-2).



PTS 1-5 = STRUCTURAL ANALYSIS POINTS

Δ = TAIL LOAD CORRECTION

6 = WGT SAVING FOR A 23.5-INCH FORWARD CG FOR DUCT HEATER (5C)

7 (5C) = LOCATION PLUS PROPULSION SYSTEM WEIGHT REDUCTION FOR DUCT HEATER (5C)

FIGURE 5-19. STRUCTURAL WEIGHT CHANGE FOR ENGINE LOCATION AND SIZE

Table 5-2 compares the weight of the airplane with VSCE 502D engines (-5G) to the turbojet baseline (-5A). Bare engine weight of the VSCE 502D is 7624 lb (3458 kg) each. The nozzle, reverser and ejector are an additional 2212 lb (1003 kg). This compares to 12,942 lb (5870 kg) and 4040 lb (1833 kg), respectively, for the baseline -5A. Total propulsion system weight is 41,400 lb (18,779 kg), which is 28,790 lb (13,059 kg) less than the turbojet baseline and 18,531 lb (8406 kg) less than the mini-bypass configuration -5B.

Weight of the nacelle/inlet is 1361 lb (617 kg) lighter than the -5A baseline. The major portion of the decrease, 1262 lb (572 kg), is due to a reduction in the weight of the engine cowling. This results from an engine envelope 47 inches (119 cm) shorter and 18 inches (46 cm) less in diameter than the baseline. The remaining 99 lb (45 kg) reflects a reduction in inlet weight, which is primarily due to a decrease in capture area.

The structural weight increment includes differences in pylon and engine support weight, along with differences in wing and fuselage weight, due to changes in load. The 2380 lb (1080 kg) reduction estimated for this increment is extrapolated from results of structural optimization studies of the baseline and mini-bypass configurations. The weight penalty for flutter and aeroelasticity is 3173 lb (1439 kg). This penalty is derived as a part of the structural/weight optimization analysis (see Structural Analysis paragraph). Further details of this analysis are presented in Section 4 of the basic report.

Minimum ground to tail bumper clearance, at maximum rotation, establishes the length of the main gear strut. To maintain the same fuselage attitude

during ground operations, a change in length of the main gear strut must be accompanied by an equivalent change in the length of the nose gear strut. Accordingly, due to the shorter VSCE 502D engine installation, both the main and nose gear struts, of the -5G configuration, have been shortened 23 inches (58 cm). This results in a 1080 lb (490 kg) saving in gear weight and a 212 lb (96 kg) saving in gear door and jamb weight. Door weights are accounted for under wing and fuselage structure. The change in wing weight also includes a 370 lb (168 kg) increase due to an increase in the span of the flaps. The flap extension is required to fill gaps left by the smaller diameter engine installation.

The mean inlet location of the VSCE 502D engines is 21.75 inches (55 cm) aft of the turbojet baseline (sta. 2521.75 versus sta. 2500). The c.g. of the engine installation, however, is 5 inches (13 cm) forward of the baseline. This anomaly results from the much shorter engine installation. The forward c.g. shift of the engine installation couples with the savings in engine and structure weight to move the OEW c.g. of the airplane 47 inches (119 cm) forward. (Note that, since the bulk of the weight saved is aft of the current c.g., its effect is to move the c.g. forward.) Total OEW saving over the -5A baseline is 33,140 lb (15,034 kg).

TABLE 5-2
WEIGHT COMPARISON – CONFIGURATION 5G (P&WA 502D)
WITH 5A BASELINE (TURBOJET)
ENGLISH UNITS

CONFIGURATION	WEIGHT – POUNDS		
	5A TURBOJET	5G VSCE-502D	DIFF.
ITEM			
WING	75,347	75,549*	+202
H-TAIL	3,960	3,960*	0
V-TAIL	3,807	3,807*	0
FUSELAGE	47,713	47,669*	–44
LANDING GEAR	36,792	35,712	–1080
FLIGHT CONTROLS	9,115	9,115	0
NACELLE/INLET	14,730	13,369*	–1361
PROPULSION (LESS FUEL SYSTEM)	70,190	41,400	–28,790
FUEL SYSTEM	3,820	3,820	0
EMERGENCY POWER UNIT	950	950	0
INSTRUMENTS	1,227	1,227	0
HYDRAULICS	5,684	5,684	0
PNEUMATICS	1,332	1,332	0
ELECTRICAL	4,850	4,850	0
NAVIGATION AND COMMUNICATIONS SYSTEM	2,756	2,756	0
FURNISHINGS	24,478	24,478	0
AIR CONDITIONING	4,854	4,854	0
ICE PROTECTION	489	489	0
HANDLING PROVISIONS	90	90	0
PENALTY – FLUTTER AND AEROELASTICITY	2,860**	3,173	+313
STRUCTURAL WEIGHT INCREMENT	––	–2,380	–2,380
MANUFACTURER'S EMPTY WEIGHT (MEW)	315,044	281,904	–33,140
OPERATIONAL ITEMS	8,096	8,096	0
OPERATIONAL EMPTY WEIGHT (OEW)	323,140	290,000	–33,140

*THE WEIGHT INCREMENT FOR STRENGTH, ETC., FOR THESE ITEMS IS INCLUDED UNDER THE ITEM STRUCTURAL WEIGHT INCREMENT AND LISTED SEPARATELY.

**2000 LB FOR ROLL AND CONTROL EFFECTIVENESS
860 LB FOR FLUTTER OPTIMIZATION

TABLE 5-2
WEIGHT COMPARISON – CONFIGURATION 5G (P&WA 502D)
WITH 5A BASELINE (TURBOJET)
METRIC UNITS

CONFIGURATION	WEIGHT – KILOGRAMS		
	5A TURBOJET	5G VSCE-502D	DIFF.
ITEM			
WING	34,177	34,269*	+92
H-TAIL	1,796	1,796*	0
V-TAIL	1,727	1,727*	0
FUSELAGE	21,643	21,622*	–21
LANDING GEAR	16,689	16,199	–490
FLIGHT CONTROLS	4,135	4,135	0
NACELLE/INLET	6,682	6,064	–618
PROPULSION (LESS FUEL SYSTEM)	31,838	18,779	–13,059
FUEL SYSTEM	1,733	1,733	0
EMERGENCY POWER UNIT	431	431	0
INSTRUMENTS	557	557	0
HYDRAULICS	2,578	2,578	0
PNEUMATICS	604	604	0
ELECTRICAL	2,200	2,200	0
NAVIGATION AND COMMUNICATIONS SYSTEM	1,250	1,250	0
FURNISHINGS	11,103	11,103	0
AIR CONDITIONING	2,202	2,202	0
ICE PROTECTION	222	222	0
HANDLING PROVISIONS	41	41	0
PENALTY – FLUTTER AND AEROELASTICITY	1,297**	1,439	+142
STRUCTURAL WEIGHT INCREMENT	––	–1080	–1080
MANUFACTURER'S EMPTY WEIGHT (MEW)	142,905	127,871	–15,034
OPERATIONAL ITEMS	3,672	3,672	0
OPERATIONAL EMPTY WEIGHT (OEW)	146,577	131,543	–15,034

*THE WEIGHT INCREMENT FOR STRENGTH, ETC., FOR THESE ITEMS IS INCLUDED UNDER THE ITEM STRUCTURAL WEIGHT INCREMENT AND LISTED SEPARATELY.

**907 kg FOR ROLL AND CONTROL EFFECTIVENESS
390 kg FOR FLUTTER OPTIMIZATION

AIRPLANE PERFORMANCE

Aerodynamics Analysis

The trimmed lift and drag characteristics for the VSCE 502D powered aircraft are obtained by adjusting the wave drag of the baseline turbojet powered aircraft for the difference due to the VSCE 502D nacelles. The difference in nacelle skin friction drag is accounted for in the installed propulsion system performance. The wave drag program predicts a reduction in supersonic wave drag of 4.61 counts (ΔC_D = .000461) due to the differences in nacelle shape and location. The characteristics used to determine the mission performance for the VSCE 502D powered aircraft are obtained by subtracting this increment from the wave drag of the baseline turbojet powered aircraft.

Performance Results

Estimated performance characteristics for the VSCE 502D powered aircraft are presented in Figures 5-20 through 5-22 as a function of engine size. The mission profile and fuel reserve ground rules are the same as used for the baseline turbojet aircraft (Figure 1-20 of the basic report). The takeoff gross weight is held constant at 750,000 lb (340,194 kg) and the payload is fixed at 55,965 lb (25,385 kg).

Figure 5-20 presents the takeoff characteristics and the height above the runway at 3.5 n.mi. (6.5 km) from the start of takeoff with the throttle cut back to meet the 4 percent all-engine climb gradient requirement of FAR Part 36. The characteristics of the aircraft with the engine size selected as described in the engine sizing paragraph are indicated on the figure. The performance of the baseline turbojet aircraft (-5A) is also shown for reference.

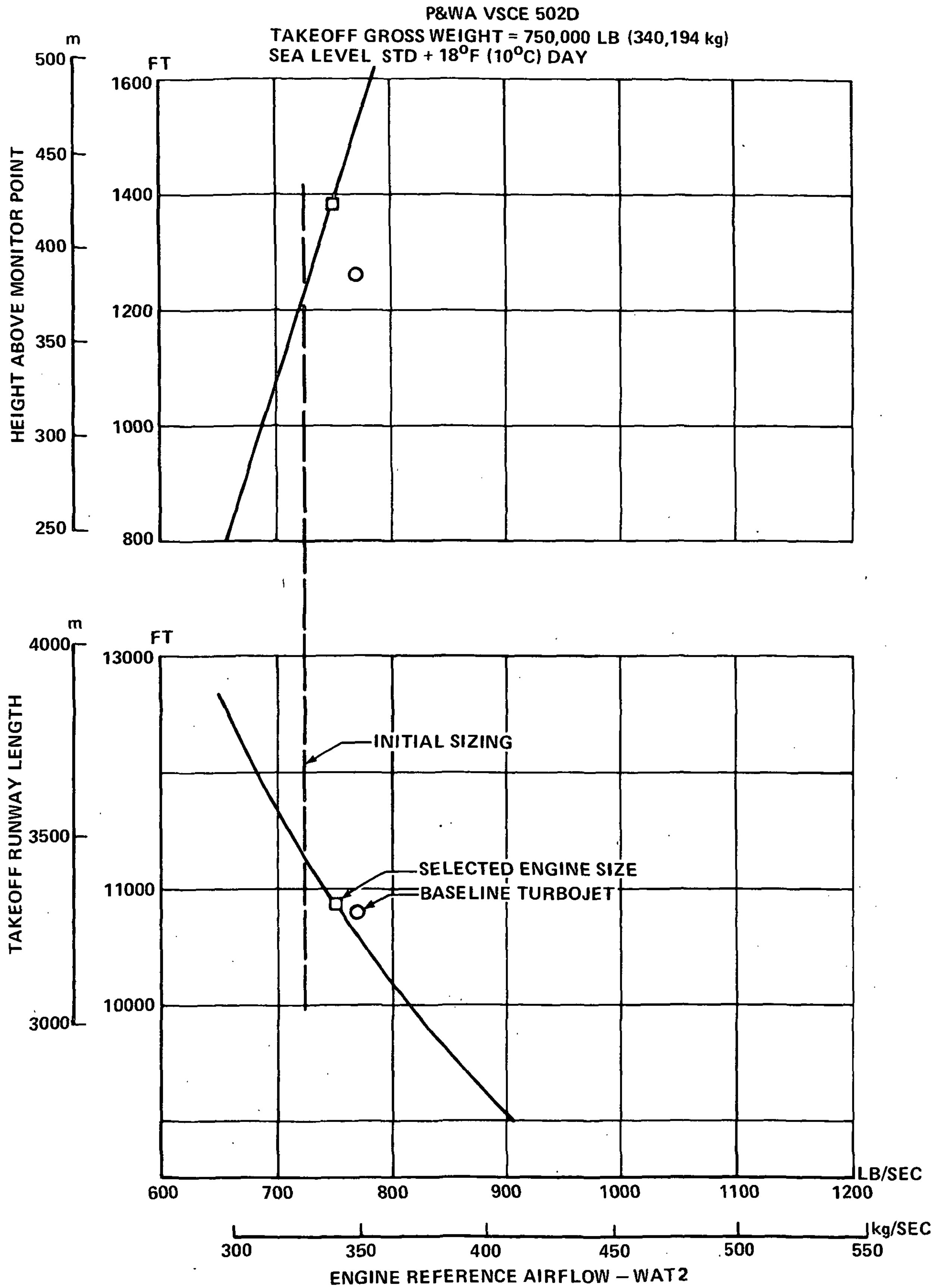


FIGURE 5-20. EFFECT OF ENGINE SIZING ON TAKEOFF PERFORMANCE

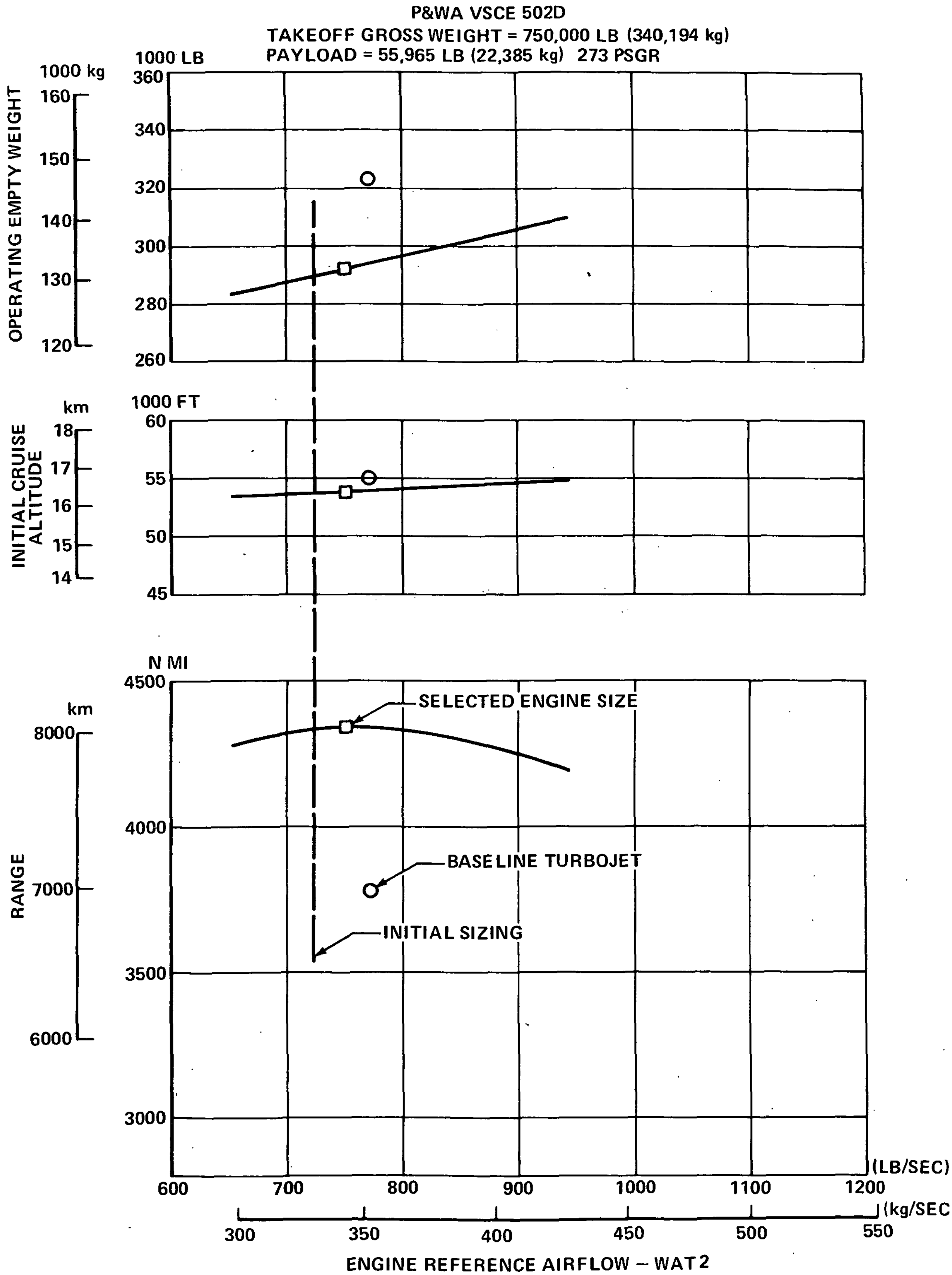


FIGURE 5-21. EFFECT OF ENGINE SIZE ON MISSION PERFORMANCE

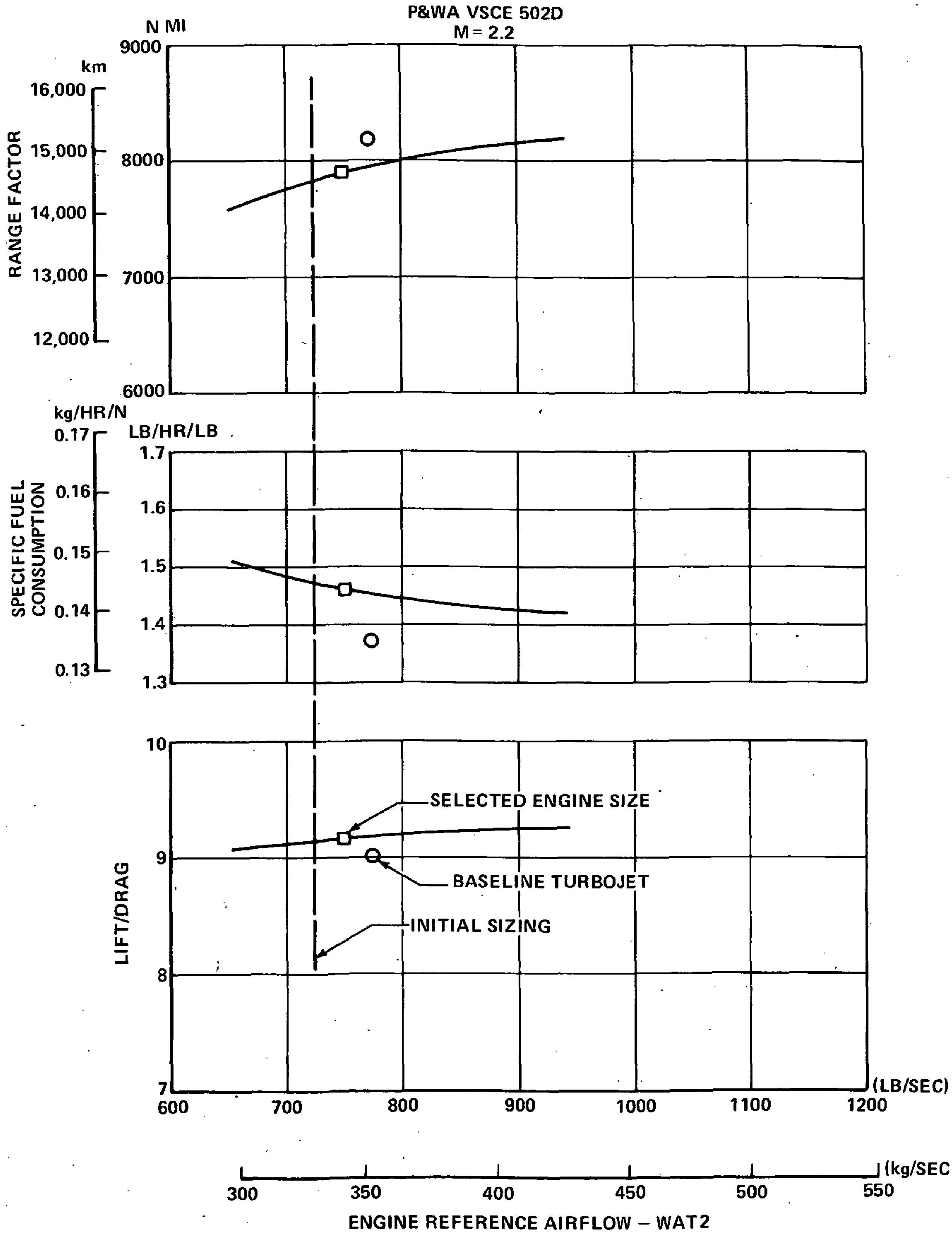


FIGURE 5-22. EFFECT OF ENGINE SIZE ON CRUISE PARAMETERS

Figure 5-21 presents the variation of operator's weight empty with engine size used for the mission performance calculations, the altitude for maximum range factor at the start of the 2.2 M cruise, and the mission range. The selected engine size [750 lb/sec (340 kg/sec)] as indicated in the figure is slightly larger than that specified in the engine sizing paragraph. The larger size is chosen at the peak of the range curve for maximum range. Further, significant gains in the takeoff field length and height above the takeoff noise monitor point are available without sacrificing sideline noise. Figure 5-22 presents the effect of engine size on the optimum cruise L/D, cruise installed SFC and the 2.2 M cruise range factor.

The data presented in the last two figures account for the changes with engine size of engine and nacelle weight, and inlet and nacelle drags, but neglect the changes in aircraft wave drag. For a ten percent change in engine size, this effect is quite small, but it can be significant for the larger engine sizes.

The performance for the VSCE 502D powered aircraft with the 750 lb/sec (340 kg/sec) engine is summarized below:

Takeoff Gross Weight	750,000 lb (340,194 kg)
Payload	55,965 lb (25,385 kg)
Takeoff Field Length	10,850 ft (3,307 m)
Height at 3.5 n.mi. (6.5 km)	1,380 ft (420 m)
Range	4,335 n.mi. (8,005 km)
Initial Cruise Altitude	54,000 ft (16,460 m)
Direct Operating Cost (1973 $)	1.79 cents/seat n.mi.

The variation in range vs. initial subsonic leg length is shown in Figure 5-23. For a 600 n.mi. (1110 km) initial subsonic leg, the range penalty is 3 percent.

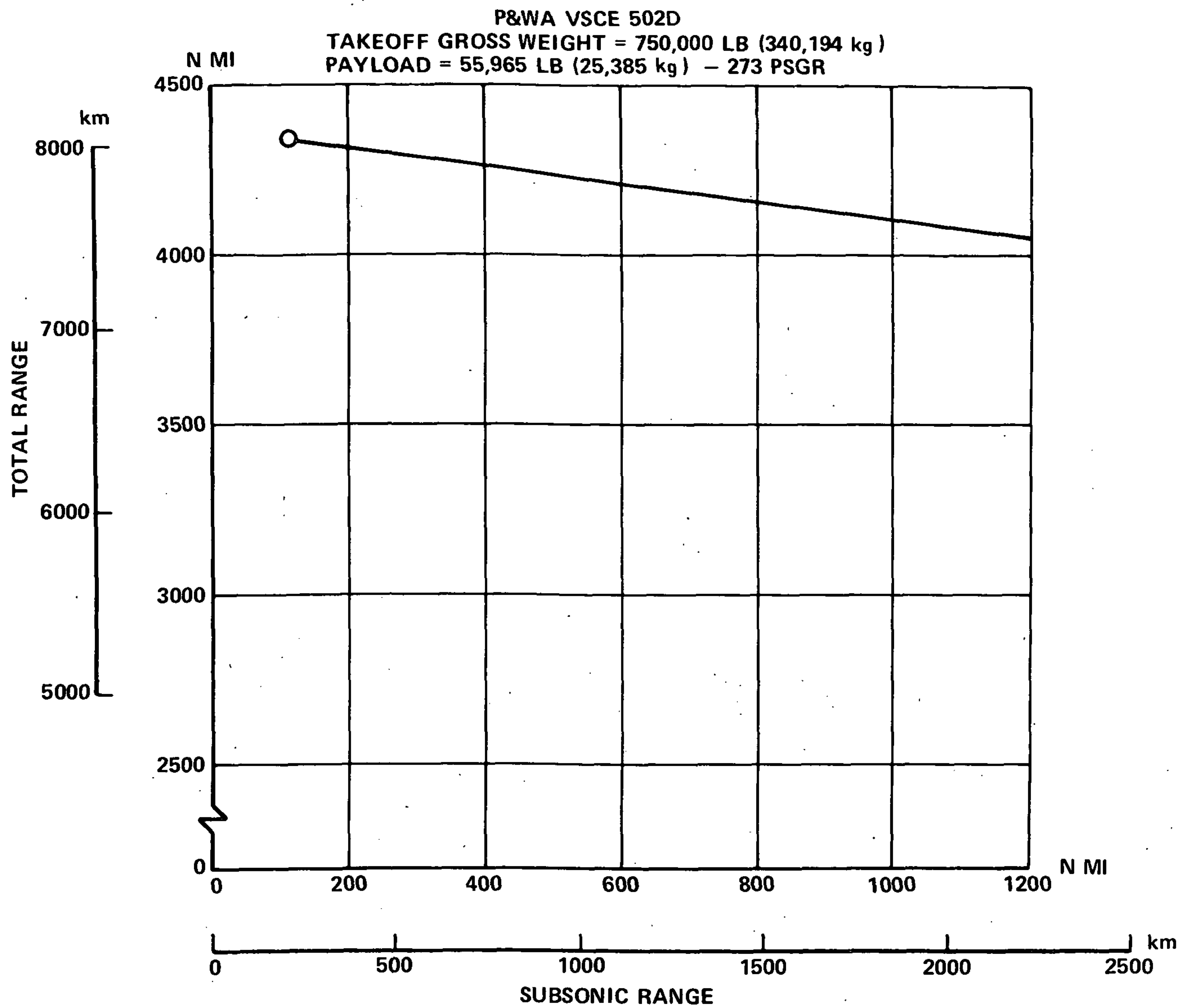


FIGURE 5-23. EFFECT OF INITIAL SUBSONIC LEG ON RANGE